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Assessing the Releases and Costs Associated with Truck Transport of Hazardous Wastes

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This report estimates the releases from and costs of the truck transport of hazardous waste. The report contains these estimates for bulk and container shipments. This study is a component of a larger analysis of hazardous waste management, EPA's "RCRA Risk-Cost Analysis Model." Transport releases are presented as the sum of (1) the expected fraction released enroute (ranging from 10^{-8} to 10^{-6} per mile) and (2) the expected fraction released at terminal points (ranging from 10^{-6} to 10^{-3} per shipment). The report estimates, using a cost formula, average costs of $4 to $5 per mile, depending on the type of transport. To make these estimates, ~~we reviewed~~ existing studies and evaluated state and national data on accident rates, quantities released in accidents, distance of shipments, numbers of shipments, quantities shipped, and component costs. → were evaluated.

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EXECUTIVE SUMMARY

In response to a growing concern over the management of hazardous wastes and their impact on the population and environment, the Resource Conservation and Recovery Act (RCRA) was enacted in 1976. RCRA authorized the EPA to establish a hazardous waste control program for the nation, which includes the identification and classification of hazardous wastes, requirements for owners and operators of hazardous waste facilities, and guidelines for state programs developed under the act.

In 1981, as part of the national hazards waste control program, EPA's Office of Solid Waste began to develop its RCRA Risk/Cost Analysis Model. The model is designed to assist in the development of hazardous waste policies.

The RCRA Risk/Cost Analysis Model consists of an array of possible ways to treat, transport and dispose of the hazardous wastes generated in the United States. There are three main factors considered in the model's formulation of possible ways to manage hazardous waste:

(1) The type of waste (and its hazardous chemical constituents).

(2) The types of technologies used to treat, transport and dispose of the wastes.

(3) The environmental settings in which the wastes are treated, transported and disposed.

The model forms all possible combinations of a list of wastes, technologies and environmental settings -- or W-E-T cells. The model then calculates the risks and costs involved in each W-E-T cell. In this fashion, the relative merits and drawbacks of various hazardous waste management strategies can be identified.

This report focuses on one component of the RCRA Risk/Cost Analysis Model: the costs incurred and expected fraction released (R_{tr}) during transport of hazardous wastes. The objectives of our project were governed by the following criteria:

- In order to establish a tool for policy analysis, we wanted to estimate a fraction release model that reflected, as much as possible, actual data on hazardous waste shipments and incidents. Compiling a comprehensive data sample necessitated extensive data collection at both the state and federal levels.
- In order to ascertain whether previous studies were reliable for policy analysis, we performed a critical review of existing truck transport cost studies. We then developed revised cost formulas to account for deficiencies identified in the review process and compared the revised cost procedure with quoted rates to validate its applicability.

Because 90 percent of all current hazardous waste transport is via truck, the transport release model and cost review were restricted to truck transport.[1]

---

[1] The authors are presently conducting studies of the release rates and costs of hazardous waste shipments by rail and waterborne transport.

Fraction Release Analysis Methodology

Hazardous waste releases during transport can result from a number of causes (failures modes) and can occur either at shipping terminal points or enroute. We defined three incident types:

(1) Container failures due to vehicular accidents enroute.

(2) Container failures occurring enroute due to causes other than vehicular accidents.

(3) Container failures at shipment terminal points.

We formulated a Transport Release Model to compute the expected fraction released (R_{tr}) during transport. This is a function of: (1) the expected fraction released enroute and (2) the expected fraction released at terminal points. Deriving these release fractions requires an understanding of the expected fraction released given an incident for each failure mode, the probability of an incident for each failure mode and, for enroute incidents, the distance shipped. It is necessary to estimate these parameters for each container type used in transport. Thus, the total number of parameters to be estimated depends on the number of container types and failure modes. Furthermore, the use of the model for policy analysis requires hazardous waste shipment distances as input.

Estimating incident probabilities also requires a determination of the total involvement. For example, total involvement for incidents which occur enroute is a function of the total distance shipped (i.e., the average shipment distance multiplied by the number of shipments). For incidents which occur at terminal points, the total involvement is the total number of shipments. Thus, it is necessary to estimate the average shipping distance and the number of shipments for each container type.

We computed these measures using: (1) shipping distances derived from incident data, 2) data on the number of vehicular accidents and 3) independently derived estimates of vehicular accident rates. Subsequently, it became possible to compute incident rates for other failure modes. It was not necessary to perform this explicitly for each container type. Rather, we expressed all incident rates in terms of a common vehicle accident rate. We assumed that this accident rate does not depend on the container type used for shipment.

Data Description

We identified three types of data which were necessary to conduct the release and cost analyses:

(1) Truck accident and volume data.
(2) Hazardous waste shipment information.
(3) Hazardous waste incident data.

Wherever possible, we obtained data from 1980, 1981 and 1982, because they represent the most recent information available on hazardous waste incidents and shipments.

We obtained truck accident and volume data from Texas, California and New Jersey records. Each record included average daily counts of vehicular traffic characterized by vehicle type and the annual number of truck accidents. The California and Texas data included observations for interstate highways, U.S. highways and state routes. The New Jersey data, on the other hand, included many highway sections containing intersections with traffic signals.

We collected data on hazardous waste shipments from California, Texas, Massachusetts and New York manifest records. In general, each record contained the following information: origin location, destination location, waste type transported, quantity shipped and unit of shipment. A significant problem with this database was its lack of accuracy in reporting the locations of generation and disposal sites. In some cases, the county of origin or the destination state was the only location description. Thus, it was necessary to make some assumptions to correct for this problem. State data also did not consistently include interstate shipments.

The primary data source for estimating the incident probability and fraction release parameters was the Hazardous Material Incident File (HAZMAT) maintained by the U.S. Department of Transportation's Materials Transportation Bureau (MTB). HAZMAT, a compilation of nationwide data on hazardous material spills, contains information on the frequency and circumstances (container involvement, failure mode, severity of resulting spills, etc.) surrounding hazardous material incidents.

Although over 8,000 incidents of hazardous material spills involving truck travel were reported in 1981, a closer inspection of these data indicated that an extremely small number (84) of these spills involved hazardous wastes. Because the sample size of hazardous waste incidents was not large enough for statistical analysis, we considered all of these hazardous materials incidents in developing the incident model. Also, because we postulated that the incident rate and fraction release models do not depend on the type of waste being shipped, but rather, on the container type used, and because the HAZMAT file covers a wide range of container types, this approach is justified.

Estimating the Truck Accident Rate

We assumed that the truck accident rate is a function of the highway type and traffic conditions. Truck accident and volume data were obtained from California, Texas and New Jersey; these data represented a wide range of traffic and truck volumes and four different highway types. To test the statistical significance of any differences in accident rates under different highway and traffic conditions, we conducted an analysis of variance (ANOVA), which indicated the significance of the traffic volume, truck percentages and highway type.

The analysis of the accident rate data yielded the following estimate for aggregate accident involvement rates (releasing accidents per million truck miles):

Interstates	0.13
U.S. and State Highways	0.45
Urban	0.73
Composite	0.28

These results fall within the range of previously reported estimates and demonstrate the difference in the accident rate for various highway types. The truck accident rate is also dependent on both the total traffic volume and the percentage of trucks in the traffic stream. These results suggest that in applying the estimates provided, cell means should be used in lieu of aggregate means if sufficient information is available to identify the highway type and the traffic volume.

Incident Modeling

The HAZMAT file of reported hazardous materials incidents allows the coding of up to 334 container types and 27 failure modes. From our analyses of these data, we identified 8 container types with reasonably uniform physical characteristics and incident involvement rates:

(1) Cylinders
(2) Cans
(3) Glass
(4) Plastic
(5) Fiber Boxes
(6) Tanks
(7) Metal Drums/Pails
(8) Open Metal Containers

For each of these container classes, we determined the respective parameters in the fraction release model. Table 1 summarizes the resulting estimates of the fraction released by container type.

The results of our analyses indicate that in terms of their order of magnitude, the expected fractions released per mile shipped range from 10^{-8} to 10^{-6}, depending on the container class. The expected fractions released at terminal points range from 10^{-6} to 10^{-3}, depending on the container class.

Table 1 Estimates of Fraction Released by Container Class

Container Class	Expected Fraction Released Per Mile Shipped**	Expected Fraction Released at Terminal Points
1	$1.3 \times 10^{-6} + (.13\ \lambda')$	1.4×10^{-4}
2	$2.6 \times 10^{-6} + (.12\ \lambda')$	4.0×10^{-4}
3	$1.7 \times 10^{-6} + (.27\ \lambda')$	2.6×10^{-4}
4	$4.1 \times 10^{-6} + (.14\ \lambda')$	5.2×10^{-4}
5	$1.3 \times 10^{-6} + (.12\ \lambda')$	6.1×10^{-5}
6	$4.2 \times 10^{-8} + (.19\ \lambda')$	7.6×10^{-6}
7	$2.4 \times 10^{-6} + (.10\ \lambda')$	2.9×10^{-4}
8*	7.5×10^{-6}	1.2×10^{-3}

---

*estimate associated with the release fraction during accident is not reliable.

**λ' = releasing vehicle accident rate.

Our computed estimates indicate that:

(1) The release rates for tank trucks are much lower than for other container types.

(2) The expected amount released at terminal points is one to three orders of magnitude higher than the amount released enroute.

(3) The expected release fractions during transport are potentially as high as the release fractions at disposal sites and treatment facilities, which range from 10^{-7} to 10^{-3} for routine spillage and 10^{-5} to 10^{-3} for accidental spillage.

Estimating the Expected Amount Released

Using the model parameters given in the previous sections, we employed the following procedure to estimate the expected fraction released during transport:

(1) Identify shipment characteristics.
  - number of shipments
  - volume per shipment
  - trip distance
  - container type

(2) Identify highway characteristics.
  - highway type
  - traffic volumes

(3) Select appropriate values of fraction release parameters for the container type being considered.

(4) Compute the fraction of accidents that involve releases

(derived as the truck accident rate multiplied by 0.2).

(5) Determine fraction released enroute and at terminal points.

(6) Multiply fraction released enroute by total trip miles and fraction released at terminal points by the number of shipments.

(7) Add these values to arrive at total expected fraction released.

(8) Multiply this by the total volume to obtain the total expected amount released.

This procedure is demonstrated in the discussion on model application.

Estimating the Cost of Transporting Waste

Trip Profile Analysis

Using the waste shipment data from Texas, California, Massachusetts and New York, we examined the following:

(1) The mean shipping distance, segmented by waste type (for each state).

(2) The quantity shipped, segmented by waste type (for each state).

(3) The extent to which the above measures vary across states.

The resulting information was used in cost applications where specific trip lengths and the quantities shipped were not known.

In order to determine if the quantity and/or distance shipped is related to the waste type (solid or liquid) or the particular state under consideration, we conducted a multivariate analysis of variance.

The results of the analysis indicated that the shipment characteristics of liquid and solid wastes vary by state and consequently we could not derive aggregate estimates. This resulted in our conducting separate analyses for each state.

Our analysis results indicated that trip distance and quantity shipped vary by waste category and also vary considerably among states. This is likely due to differences in the manifest system, geographic location, size and industrial activity of each state.

We did, however, conclude that the quantity transported is independent of trip distance. Our findings do not substantiate the argument that shipments are filled closer to capacity on longer trips than shorter ones. We also found that in three of the four states, the mean shipment size for liquids is larger than for solids shipments, and that in three of the four states, the average trip distance is longer for solids shipments than for liquids shipments.

Questions are sometimes raised regarding general waste shipment characteristics for the United States. Although there is no basis for assuming that our sample is typical of the entire hazardous waste transport industry, we computed weighted averages of the shipping distances and quantities which reflect the number of annual manifests in each of the states. These weighted averages should not be misinterpreted to apply to specific hazardous waste transport scenarios in the United States.

The mean trip length for all shipments is 84.2 miles, with a mean trip length for liquids of 77.1 miles and for solids of 109.6 miles. For liquids, the mean quantity shipped is 3,171 gallons. For solids, it is 2,791 gallons (11.6 tons). The trip distance frequency distribution for all four states, for both liquids and solids, follows an exponential distribution. This is not surprising because disposal sites are likely to be located near points of waste generation.

Cost Methodology

We reviewed the existing literature on the cost of transporting hazardous waste and identified seven studies which treated the issue of estimating the cost of transporting hazardous waste by truck. All seven studies considered this issue within the larger framework of the total cost and risk of hazardous waste treatment at a regional level.

The studies' results varied from gross estimates of the unit cost of transport to more sophisticated derivations of costs based on fixed and variable components. We noted several deficiencies in these methods, particularly in the assumptions relating to shipment characteristics (for example, all of the studies assumed that vehicles travel at capacity, which is not substantiated by the results of the trip profile analysis) and their failure to compare their results to the actual rates charged by haulers.

Using the most comprehensive of the methodologies, we developed a revised costing procedure which was designed to overcome these deficiencies. Our modifications included considering trip distances and shipment sizes based on the trip profile analysis results, using 1983 component costs, and comparing the revised methodology to actual price quotes from waste haulers.

We then used the revised costing procedure to estimate transport costs for 6,000 gallon tankers and 18-ton stake (flatbed) trucks. The average costs computed using the trip profile characteristics are:

	Tankers	Stake Trucks
Average Cost Per Loaded Mile ($)	$4.14	$4.55
Average Cost Per Loaded Ton-Mile ($)	$0.31	$0.39

The average costs per loaded mile and loaded ton-mile are larger for stake trucks than tankers. This is due to the smaller loads associated with stake trucks.

In order to estimate the cost of transport when details on specific shipments are available, we derived the following formulas for tankers and stake trucks:

$$\text{clm}_{\text{tanker}} \text{ (\$/loaded mile)} = 3.08 + \frac{88.8}{X}$$

$$\text{cltm}_{\text{tanker}} \text{ (\$/loaded ton-mile)} = \frac{3.08}{Y} + \frac{88.8}{XY}$$

$$\text{clm}_{\text{stake}} \text{ (\$/loaded mile)} = 3.02 + \frac{129.38}{X}$$

$$\text{cltm}_{\text{stake}} \text{ (\$/loaded ton-mile)} = \frac{3.02}{Y} + \frac{129.38}{XY}$$

where:

clm = cost per loaded mile

cltm = cost per loaded ton-mile

X = shipment distance (miles)

Y = shipment size (tons)

To determine the accuracy of the revised costing procedure, we compared its estimates with the actual rates charged by haulers. The comparison showed that the estimates we obtained using this cost formula appear to be quite representative of quoted rates in the hazardous waste transport industry. The average cost figures, however, did not compare quite as favorably. Consequently, we recommend that the average cost figures should be used rather carefully, and should only be employed when information is not available on trip distance and/or shipment size.

Model Application

To illustrate the established release and cost procedures, we posed the following problem:

Suppose 200 55-gallon drums are being shipped a distance of 100 miles on interstate highways. The average daily traffic (ADT) and truck percentages on the highways are unknown. What are the expected releases and cost involved?

Release Computation

From previously reported results, we obtained the releasing accident rate for interstates as 0.13×10^{-6} releasing accidents per truck mile. The expected amount released enroute was obtained using the fraction released from Table 1 as:

$$E\ (\text{release enroute}) = (2.4\times10^{-6} + 0.10\times0.13\times10^{-6}) \times 100 \times 200 \times 55$$
$$= 2.65 \text{ gallons}$$

$$E \text{ (release at terminals)} = 2.9\times10^{-4} \times 200 \times 55$$
$$= 3.19 \text{ gallons}$$

Total expected release = 5.84 gallons

Cost Analysis

The average load carried by stake trucks is 2,791 gallons, which is equivalent to 11.6 tons. The quantity being shipped is 11,000 gallons, which is equivalent to 45.83 tons. The cost per loaded ton-mile is:

$$\text{cltm}_{\text{stake}} \text{ (\$/loaded ton-mile)} = \frac{3.02}{11.6} + \frac{129.38}{(100)(11.6)} = 0.37$$

Number of ton-miles per shipment = 11.6 x 100 = 1160

Cost per shipment = 1160 x 0.37 = $429.20

Average number of shipments = 3.94

Total Cost = 3.94 x 429.20 = $1,691.05

Concluding Remarks

This project has addressed the potential releases and costs of transporting hazardous wastes by truck. In the course of conducting this study, we drew several conclusions that are useful for policy analysis. Below, we briefly discuss our conclusions.

A trip profile analysis conducted on data from several states indicated that, on average, wastes are shipped less than 100 miles from their generation to their disposal sites. The average trip length is lower for liquids than for solids. Generally speaking, the mean quantity shipped is independent of shipping distance.

In assessing truck transport releases, it is important to distinguish between two kinds of incidents that result in spills. For one class of incidents, the probability of occurrence is a function of the distance traveled; for the other, the occurrence probability for a particular shipment is fixed. We computed expected fraction release estimates for both kinds of incidents.

The costs of transporting hazardous wastes by truck can be reasonably approximated using the formulas derived in this study. These cost formulas compare well with actual industry quotes.

The individual and collective results of the entire analysis are applicable at many levels of aggregation. Using this study's models and cost formulas, it is possible to obtain broad estimates of expected releases and transport costs, as well as estimates of the releases and costs involved in individual shipments.

Perhaps the most important result of this study is that the release rates associated with transporting hazardous wastes by truck appear to be as large as the potential releases at treatment and disposal sites. In fact, for some W-E-T combinations, transport may be a potentially more dangerous activity. As a result, policymakers should give careful consideration to the relative risks involved in the treatment, transport and disposal of hazardous wastes.

CHAPTER 1

INTRODUCTION

In the United States, 160 million metric tons of hazardous wastes are generated each year as part of the industrial process. These wastes include organic chemicals, pesticides, acids, caustics, flammables and explosives [1].

Accidents involving hazardous wastes have the potential to produce catastrophic effects on people and the environment. Depending on the nature of the waste, the extent of its release and where it occurs, hazardous waste spills can impose serious public safety problems through contamination of the surrounding air, water or soil. Therefore, it is of utmost importance to dispose of these wastes with a minimal impact on the environment and to find safer methods of transporting them from their generation zones to disposal sites.

In response to a growing concern over the management of these wastes and their impact on the population and environment, the Resource Conservation and Recovery Act (RCRA) was enacted in 1976. RCRA authorized the EPA to establish a hazardous waste control program for the nation, which includes the identification and classification of hazardous wastes, requirements for owners and operators of hazardous waste facilities, and guidelines for state programs developed under the act.

In 1981, as part of the national hazards waste control program, EPA's Office of Solid Waste began to develop its RCRA Risk/Cost

Analysis Model. The model is designed to assist in the development of policies for hazardous waste facilities.

The RCRA Risk/Cost Analysis Model consists of an array of possible ways to treat, transport and dispose of the hazardous wastes generated in the United States [2]. There are three main factors considered in the model's formulation of possible ways to manage hazardous waste:

(1) The type of waste (and its hazardous chemical constituents).

(2) The types of technologies used to treat, transport and dispose of the wastes.

(3) The environmental settings in which the wastes are treated, transported and disposed.

The model forms all possible combinations of a list of wastes, technologies and environmental settings. Thus, it may be regarded as a three-dimensional matrix, each cell of which is a combination of a waste, an environment and technology(ies) - - a W-E-T cell. Each W-E-T cell may be viewed as a particular waste management practice.

The model then calculates the risks and costs involved in each W-E-T cell. In this fashion, the relative merits and drawbacks of various hazardous waste management strategies can be identified.

This report focuses on one component of the RCRA Risk/Cost Analysis Model: the costs incurred and expected fraction released (R_{tr}) during transport of hazardous wastes. The objectives of our project were governed by the following criteria:

- In order to establish a tool for policy analysis, we wanted to estimate a fraction release model that reflected, as much as possible, actual data on hazardous waste shipments and incidents. Compiling a comprehensive data sample necessitated extensive data collection at both the state and federal levels.
- In order to ascertain whether previous studies were reliable for policy analysis, we performed a critical review of existing truck transport cost studies. We then developed revised cost formulas to account for deficiencies identified in the review process and compared the revised cost procedure with quoted rates to validate its applicability.

Because 90 percent of all current hazardous waste transport is via truck [3], the transport release model and cost review were restricted to truck transport.[1]

This report is organized as follows. Chapter 2 develops the framework for the fraction release analysis and discusses the data requirements. Chapter 3 summarizes the data collection effort and describes the format of the database. Chapter 4 describes an analysis of shipment characteristics performed on hazardous waste manifest data from several states. Chapters 5 and 6 focus on the estimation of the parameters for the fraction release model. Chapter

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[1] The authors are presently conducting studies of the release rates and costs of hazardous waste shipments by rail and waterborne transport.

7 describes the procedure for estimating the cost of transporting wastes by truck. Chapter 8 provides examples demonstrating the use of the fraction release and cost models, as well as some concluding remarks. The appendices present the report's supporting documentation.

CHAPTER 2

FRACTION RELEASE ANALYSIS METHODOLOGY

Hazardous waste releases during transport can result from a number of causes (failures modes) and can occur either at shipping terminal points or enroute. Of those incidents which occur enroute, a certain proportion results directly from truck accidents. We defined three incident types as:

(1) Container failures due to vehicular accidents enroute.

(2) Container failures occurring enroute due to causes other than vehicular accidents.

(3) Container failures at shipment terminal points.

In developing the transport release model, four postulates were made for these three types of incidents:

(1) The probability of a truck accident in which a release occurs is independent of the waste being shipped and the container type used in shipment.

(2) The probability of occurrence of an incident at any point along the route is a nonzero constant which, exclusive of truck accidents, depends on the container type used.

(3) The probability of occurrence of an incident at a shipping terminal point depends only on the container type used.

(4) The expected amount released as the result of an incident depends on the container type used and the specific cause of the release (failure mode). It does not

depend on the location of the incident.

We formulated the Transport Release Model as follows:

$$R_{tr} = \begin{cases} \underline{R} \times \underline{\Lambda} \times d & \text{Expected fraction release enroute.} \\ \underline{R} \times \underline{\theta} & \text{Expected fraction released at terminal points.} \end{cases}$$

where: R_{tr} is the expected release fraction.

$\underline{R}$ is a vector of parameters corresponding to the expected fraction released of hazardous wastes for each defined failure mode.

$\underline{\Lambda}$ is the probability vector corresponding to incidents enroute for each defined failure mode.

$\underline{\theta}$ is the probability vector corresponding to incidents at terminal points for each defined failure mode.

d is the distance shipped.

For each container type considered, it is necessary to estimate the vectors $\underline{R}$, $\underline{\theta}$ and $\underline{\Lambda}$. Thus, the total number of parameters to be estimated depends on the number of container types and defined failure modes. Furthermore, the use of the model for policy analysis requires hazardous waste shipment distances as input.

The primary data source for estimating the incident probability and fraction release parameters in this analysis was the Hazardous Material Incident File (HAZMAT) maintained by the U.S. Department of Transportation's Materials Transportation Bureau (MTB). A compilation of nationwide data on hazardous material spills, HAZMAT contains information relating to the frequency and circumstances (container involvement, failure mode, etc.) surrounding hazardous material incidents.

Estimating incident probabilities also requires a determination of the total involvement. For example, total involvement for incidents which occur enroute is a function of the total distance shipped (i.e., the average shipment distance multiplied by the number of shipments). For incidents which occur at terminal points, the total involvement is the overall number of shipments. Thus, it is necessary to estimate the average shipping distance and the number of shipments for each container type.

The average shipping distance was computed from information contained directly in the HAZMAT file. We estimated the number of shipments using 1) this estimate of the average shipping distance, 2) HAZMAT data on the number of vehicular accidents and 3) independently derived estimates of vehicular accident rates. Subsequently, it became possible to compute incident rates for other failure modes. It was not necessary to perform this explicitly for each container type. Rather, we expressed all incident rates in terms of a common truck accident rate. We assumed that this accident rate does not depend on the container type used for shipment.

After the Transport Release Model's framework was developed, we identified the following analyses and data requirements:

(1) Truck Accident and Volume Data

a. Compile truck accident rates for different highway types and under different traffic volume conditions.

b. Conduct statistical tests to determine the effect of highway type, traffic volume and truck volume on the accident rate.

(2) Hazardous Waste Shipment Information

a. Compile average waste shipping distance and quantity carried for several states and various waste categories (solids, liquids, etc.).

b. Conduct statistical tests to determine the effects of states and waste types on shipping distances and quantities.

(3) Hazardous Waste Incident Data

a. Identify container classes and failure modes to be considered.

b. Estimate the mean shipping distances for each container class.

c. Estimate the fraction released as a result of an incident for each container class.

d. Estimate incident probabilities for each container class.

e. Derive expected release estimates for each container class per mile shipped and at terminal points.

CHAPTER 3

DATA DESCRIPTION

The previous discussion identified three streams of data which were necessary to conduct the risk analysis:

(1) Truck accident and volume data.

(2) Hazardous waste shipment information.

(3) Hazardous waste incident data.

Wherever possible, we obtained data from 1980, 1981 and 1982, because they represent the most recent information available on hazardous waste incidents and shipments. Below, we describe the types and sources of the data gathered and the problems encountered during data collection.

3.1 Truck Accident and Volume Data

To ensure that our database was comprehensive and useful, we imposed the following rules for collecting truck accident and volume data:

(1) Obtain a statistically-large sample of highway locations for which accident histories, truck volumes and total traffic volumes are available.

(2) Obtain location samplings for different highway types. Different highway types (Interstate, U.S. routes, State, etc.) are based on different design standards and, as a result, may exhibit different accident frequencies.

(3) Obtain location samplings from several states. While the

design standards are essentially the same across states, there may be other variables which affect truck accident rates (e.g., climate).

Following these rules, we obtained accident and volume data over 5-mile sections from three states: Texas, California and New Jersey.

3.1.1 Texas

The Texas State Department of Highways and Public Transportation maintains 320 manual traffic volume count stations across the state. These stations provide average daily counts of vehicular traffic characterized by vehicle type. The Department also maintains a comprehensive accident records system from which one can obtain accident data. We obtained accident and volume data from 47 randomly selected stations (9 State, 18 U.S. Routes and 20 Interstates) for the year 1980; the format of these data is described in Table 3.1.

3.1.2 California

The California Department of Highways and Public Transportation maintains count station data in the same basic format as the Texas data. We randomly selected 95 count stations (46 State, 15 U.S. Routes and 34 Interstates) for the year 1981, and obtained bi-directional volume and accident data for 5-mile sections for each station.

3.1.3 New Jersey

The New Jersey Department of Transportation maintains classified traffic counts as well as descriptions of vehicular accidents.

Table 3.1 Truck Accident and Volume Data Format

DATA ITEM	TYPE
Station Code	Text
Station Location	Text
Highway	Text
Control section	Text
One-directional length	Real
Number of truck accident/year	Integer
Truck Average Daily Traffic (ADT)(2-axle and greater)	Integer
Total ADT	Integer

We obtained data from 52 out of 171 randomly selected count stations for 1980. The traffic volume counts from these stations were 8-hour averages for 1980. The data were not segmented by highway type because most of the sampled roadway sections contained signalized intersections. Instead, the number of intersections in the 5-mile segment of interest was recorded because we felt that intersections would influence the accident rate more strongly than highway type.

3.2 Hazardous Waste Shipment Information

Some states have implemememented a manifest system for recording hazardous waste shipments. The data from such manifest systems can be used to study the quantity and distance shipped by waste category. We obtained waste shipment data from California, Texas, Massachusetts and New York. We selected these states because they organized and maintain accessible manifest records, and the states vary in geographical location, size and in their level of industrial activity.[2]

It should be noted, however, that none of these states records information on shipping modes as part of the manifest file. In order to determine which shipments were made by truck, we assumed that a maximum shipment weight of 66,500 lbs was transportable by truck, based on information in the Oglesby and Hicks study [4].

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[2] Data availability imposed limitations on this analysis such that different states were used for accident and hazardous waste shipment analyses, respectively.

3.2.1 California

We obtained the entire manifest file from the California Department of Health Services (CDHS) in two formats, "A" and "B". The major difference between the two formats is that Format A used an alphanumeric code for the county where the shipment originated while Format B used a numeric code for the same information. The CDHS used Format A through March 1981 and Format B from April 1981 through June 1981.

The CDHS also made a reporting change in its waste code. Prior to Febrary 1981, it defined 16 waste types; the code was subsequently expanded to include 76 waste types. The reporting format allows for the possibility of three different waste types being shipped concurrently, but the details of the shipment refer only to the first waste code noted on the record. The general format of these shipment data is shown in Table 3.2.

The manifest identifies each shipment's point of origin by county, implying that any analysis of shipments would be conducted by assuming that travel originated at the county's centroid. The disposal sites are identified by name and location. The data also include out-of-state shipments, which comprise approximately 2% of all shipments. Although the data do not specify the destination state, a CDHS official estimated that 80 percent of interstate shipments are destined for Nevada.

Table 3.2 California Waste Shipment Data Format

DATA ITEM	TYPE	LENGTH
County code	Integer	2
Waste type codes	Integer	6
Hazardous properties code	Integer	1
Number of containers	Integer	3
Container type code	Integer	1
Physical state of materials code	Integer	1
Disposal site code	Integer	3
Quantity shipped	Integer	5
Units	Integer	1
Handling method code	Integer	1
Disposal date	Integer	5

3.2.2 Texas

We obtained the entire manifest file for the years 1976, 1979, 1980 and 1981 from the Texas Department of Water Resources.[3] Initially this database included all hazardous material shipments, but was subsequently modified to include only those shipments of materials which are categorized as wastes. Because the database contained very limited information regarding out-of-state disposal sites, we used only the data on disposal trips within Texas. In cases where both the shipper and receiver filed reports for the same shipment, we eliminated these duplicate records.

Each record contains the registration numbers of the shipper and receiver. We then used the master file of shippers and disposal sites to obtain the exact origin and destination location of each waste shipment. This allowed for us to make more accurate estimates of the distance traveled than in California. Table 3.3 provides a description of the Texas data format.

3.2.3 Massachusetts

We obtained a random sample of waste shipments for 1981 from Urban Systems Research and Engineering, Inc., the firm responsible for collecting hazardous waste data for the Massachusetts Bureau of Solid Waste Disposal. The sample consisted of 642 records, which includes both intrastate and interstate shipments. These data are described in Table 3.4.

Although the origin of a shipment was identified by community, its destination site was coded only by state. We obtained a separate

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[3] We requested the 1976 data in case it was necessary to perform a trend analysis.

Table 3.3 Texas Waste Shipment Data Format

DATA ITEM	TYPE	LENGTH
Report date	Integer	4
Receiver district code	Integer	2
Receiver registration number	Text	5
Shipper district code	Integer	2
Shipper registration number	Text	5
Ticket number	Integer	6
Ticket type	Text	2
Waste code	Integer	6
Quantity shipped	Integer	6
Units code	Integer	1
Date shipped	Integer	4
Comments	Text	30
Record number	Text	30

Table 3.4 Massachusetts Waste Shipment Data Format

DATA ITEM	TYPE	LENGTH
ID	Text	5
Name	Text	25
Town of origin code	Integer	3
Region of origin code	Integer	1
Month in 1981	Integer	2
Waste type	Text	2
Destination code	Integer	2
Method of disposal code	Integer	1
Generator code	Integer	4
Employment at generation site	Integer	7
Volume shipped (gals)	Integer	6

list of disposal sites which specifies each facility's exact location and the types of wastes it treats [5]. We assumed that all shipments would go to the nearest facility in the destination state that could accomodate the type of waste being transported.

3.2.4 New York

The New York data consist of a random sample of 209 records for 1982 that were randomly selected from a file of hazardous waste shipments maintained by the New York State Department of Environmental Conservation. These data include the town of origin and destination for both intrastate and interstate shipments. The waste shipment data format for New York appears in Table 3.5.

3.3 Hazardous Waste Incident Data

The U.S. Department of Transportation's Materials Transportation Bureau (MTB) collects information on hazardous materials spills from all states. We obtained their entire data file (called HAZMAT) from the National Data Corporation for the years 1976, 1980 and 1981. It should be noted that the MTB redefined the term "incident" in January 1981 to exclude all battery spills and spills of paints contained in 5-gallon cans or less, unless death, injury or excessive damage occurred.

The HAZMAT data allow for two container types to be coded for each shipment. Container type 1 is usually the inner container and container type 2 is the outer container (unless two different container types are used in the same shipment). Failure modes are used to

Table 3.5 New York Waste Shipment Data Format

DATA ITEM	TYPE
Origin (town, state)	Text
Destination (town, state)	Text
Waste type	Integer
Quantity	Integer
Units	Integer
Number of containers	Integer
Container type	Integer

describe the reasons for container failure (see Appendix B). HAZMAT allows two such modes for each container type (e.g., handling failure and loose valves). An example of each record and the information it can contain is shown in Table 3.6.

Although over 8,000 incidents of hazardous material spills involving road travel were reported in 1981, a closer inspection of the data indicated that only 84 of these spills involved hazardous wastes.[a] Because the sample size of hazardous waste incidents was not large enough for statistical analysis, we considered all hazardous materials incidents in developing the incident model. In view of the postulates made in Chapter 2 (i.e., that the incident rate and fraction release models do not depend on the type of waste being shipped, but rather, on the container type used), and the fact that the HAZMAT file covers a wide range of container types, this approach is justified.

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[a] Based on the classification of hazardous wastes used by the Materials Transportation Bureau.

Table 3.6 Hazardous Waste Incident Data Format

DATA ITEM	TYPE	LENGTH
Report number	Text	8
Multiple code	Text	1
Mode code	Text	1
Date of incident	Text	6
Time of incident	Text	4
Incident city	Text	13
Incident state	Text	2
Carriers	Text	9
Shippers	Text	9
Origin city	Text	13
Origin state	Text	2
Destination city	Text	13
Destination state	Text	2
Injuries	Integer	4
Deaths	Integer	3
Damages	Integer	8
Damage code	Text	1
Quantity released	Integer	7
Units	Text	3

Commodity code	Text	5
Commodity class	Text	2
Container 1 code	Text	8
Failure code 1 cont 1	Integer	2
Failure code 2 cont 1	Integer	2
Capacity container 1	Integer	6
Capacity units cont 1	Text	3
Number in shipment cont 1	Integer	5
Number failed cont 1	Integer	5
Gauge of cont 1	Text	6
Manufacturers of cont 1	Text	9
Label or placard	Text	7
Completeness code	Text	1
Significance of report	Text	1
General cause of incident	Text	1
Result of release	Text	1
Recommendation on report	Text	1
Apparent violation	Text	1
Miscellaneous information	Text	2
Container 2 code	Text	8
Failure code 1 cont 2	Integer	2
Failure code 2 cont 2	Integer	2
Capacity container 2	Integer	6
Capacity units cont 2	Text	3
Number in shipment cont 2	Integer	5

Number failed cont 2	Integer	5
Gauge of cont 2	Text	6
Manufacturers of cont 2	Text	9
Rail-tank-car ID no.	Text	10
Registration exemption no.	Text	6
Inspection date	Text	6
Carrier's name	Text	30
Shipper's name	Text	30
Commodity name	Text	19

CHAPTER 4

TRIP PROFILE ANALYSIS

Using the waste shipment data from Texas, California, Massachusetts and New York, we compiled the following:

(1) The mean shipping distance, segmented by waste type (for each state).

(2) The quantity shipped, segmented by waste type (for each state).

(3) The extent to which the above measures vary across states.

The resulting information was used in cost applications where specific trip lengths and the quantities shipped were not known. It also serves as useful information for policy studies which rely on characteristics of hazardous waste shipments. Below, we describe the process used to refine the database and the analysis procedure for each of the four state databases.

4.1 Data Refinement

After we eliminated records of non-hazardous waste shipments, redundancies and other reporting problems, we were left with 56,414 records for Texas (1981), 40,245 records for California (1981), and random samples of 642 records for Massachusetts (1981) and 209 records from New York (1982). For every state, we performed a sampling procedure; the sample size was such that the 95 percent confidence limits were within 30 percent of the mean (with the exception of the Massachusetts solids data[5]).

For Texas, 137 records were randomly selected from the database and for each of these records, we identified the registration of the shipper and receiver. We then obtained locations of the generation and disposal sites using the master registration file of the Texas Department of Water Resources. Finally, we used a road map to estimate trip distances.

For California, we randomly selected 242 records using a similar sampling scheme. Each record contained information on the origin county (generation site) and the disposal site location. Using road maps, we identified county centroids and estimated the trip distance from the origin centroid to the disposal site.

For New York, 193 randomly selected records out of the 209 were used in the analysis. A random sample of 233 Massachusetts records were selected based on the sampling scheme.

If the generation and disposal sites were located in the same town, we assumed a shipping distance of 10 miles for Texas, California and New York. For Massachusetts, we assumed a 5 mile shipping distance, as towns were assumed to be geographically smaller there.

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[5] Shipments of solids in Massachusetts comprised too small a share of overall shipments in the random sample to meet this criteria.

4.2 Analysis Results

In order to determine if the quantity and/or distance shipped is related to the waste type (solid or liquid) or the particular state under consideration, we conducted a multivariate analysis of variance. The results of the analysis indicated that the shipment characteristics of liquid and solid wastes vary by state and consequently we could not derive aggregate estimates. This resulted in our conducting separate analyses for each state, as described below.

4.2.1 California

The California data on the quantity of waste shipped are coded in five different units:

(1) Gallons.

(2) 42 gallon barrels.

(3) 55 gallon drums.

(4) Tons.

(5) Cubic yards.

We assumed that the first three codes constitute a liquid measure, while the last two are for solids.[6]

Figure 4.1 shows the shipping distance distribution for the overall sample. Table 4.1 displays the means and standard deviations of the shipping quantities and distances by waste type. The mean shipping distance is roughly 78 miles, with liquids being transported greater distances than solids. The latter was confirmed by a hypothesis test which was significant at the 95 percent confidence

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[6] For states where both unit codes and waste type codes were available, consistency checks were administered.

Figure 4.1 Frequency Histogram for Overall Sample - California

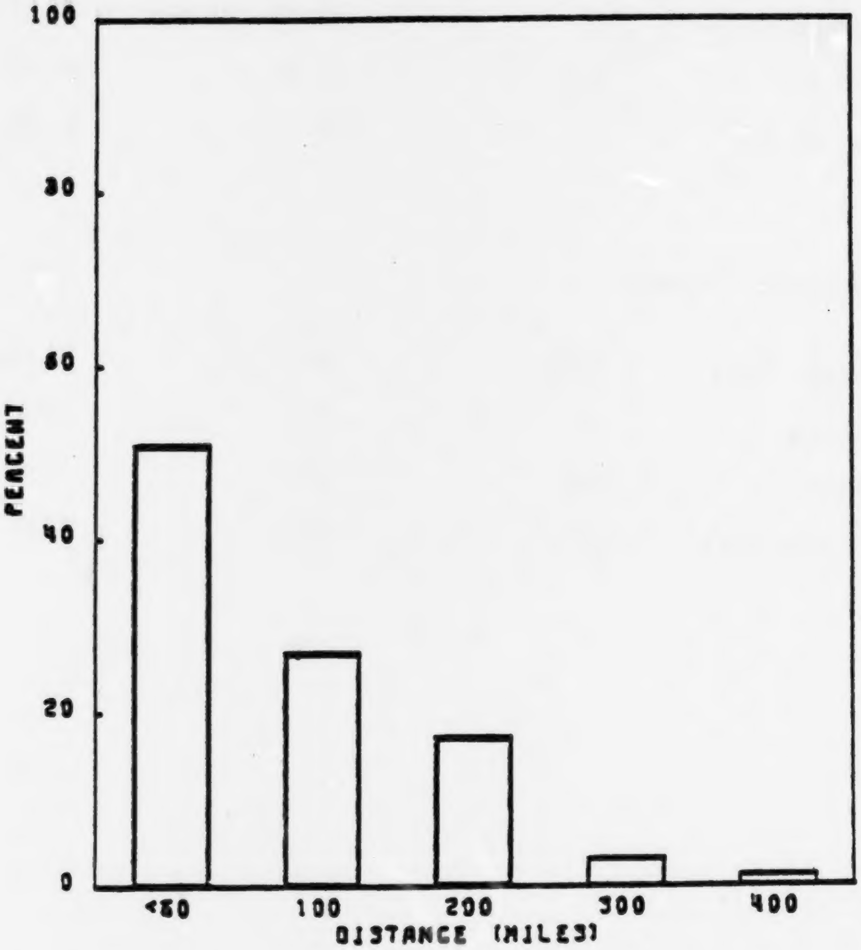


Table 4.1 Distance and Quantity Shipped - California

Distance Shipped

Waste Type	Sample	Mean	St.Dev.
Liquid	77	99.08	68.02
Solid	165	68.39	94.00
Grand Mean	242	78.16	87.62

Quantity Shipped

Waste Type	Sample	Mean	St.Dev.
Liquid	77	3156.	1719.
Solid	165	2199.	1639.
Grand Mean	242	2504.	1720.

level.

While it has been argued that haulers operate closer to capacity on long-distance runs, we found that the distance and quantities shipped are uncorrelated ($\rho = 0.15$).

On the basis of the above observations, one can conclude that, in California, shipments involving liquids travel significantly greater distances than those involving solids. Furthermore, the quantity of waste shipped is, on the average, the same for varying trip lengths. This is true both for liquids and solids.

4.2.2 Texas

The Texas data on the quantity of waste shipped are coded in the following units:

(1) Tons.

(2) Gallons.

(3) Cubic yards.

(4) 55 gallon drums.

As before, we assumed that the tons and cubic yards codes constitute a solids measure and that gallons and 55 gallon drums are for liquids. Table 4.2 displays the means and standard deviations of the shipping distances and quantities by waste type. Figure 4.2 shows the shipping distance distribution for the overall sample, which again follows an exponential form.

The mean shipping distance in Texas is approximately 57 miles, roughly 27 percent less than in California. It is interesting to note that in Texas, solids shipments travel longer distances than liquids, a

Table 4.2 Distance and Quantity Shipped - Texas

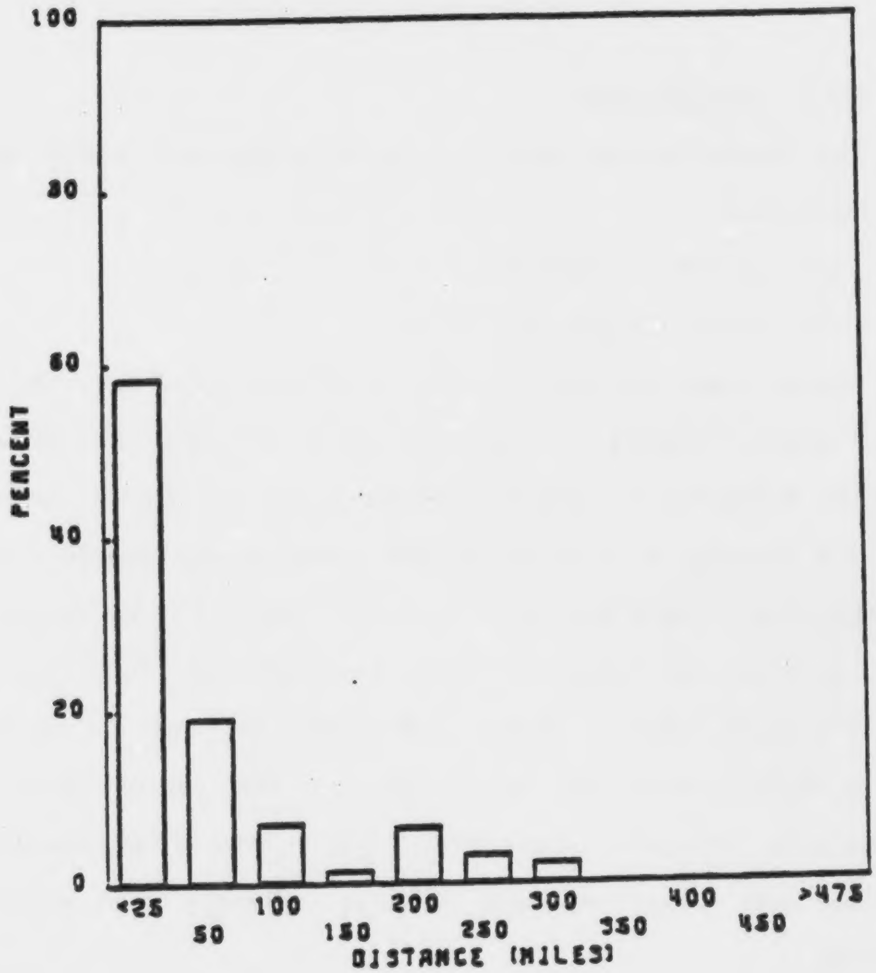
Distance Shipped

Waste Type	Sample	Mean	St.Dev.
Liquid	89	49.58	78.65
Solid	48	70.37	82.67
Grand Mean	137	56.87	80.39

Quantity Shipped

Waste Type	Sample	Mean	St.Dev.
Liquid	89	3650.	1812.
Solid	48	3390.	2041.
Grand Mean	137	3481.	1961.

Figure 4.2 Frequency Histogram for Overall Sample - Texas



reversal from the California findings. This was confirmed by a hypothesis test at the 95 percent significance level. We also found in Texas that distance and quantities shipped are uncorrelated (ρ = 0.23).

4.2.3 Massachusetts

The Massachusetts data on waste types are coded in the following units:

(1) Liquids (in gallons).

(2) Solids (in gallons).

Within these broad categories, waste types are coded by the nature of the waste (solvents, waste oils, etc.). Figure 4.3 shows the frequency histogram of shipping distances for the overall sample and Table 4.3 displays a summary of the distance and quantity shipped by waste type. Note that the mean trip length for all shipments is similar to those for Texas (57 miles) and California (78 miles), states which are much larger in size. The reason for this, of course, is that the Massachusetts data reflects the fact that approximately 25% of the waste is shipped out-of-state. As mentioned previously, the California and Texas manifest data is primarily for within-state shipments.

On the basis of the computed correlation between distance and quantity shipped, the quantity of liquids shipped appears to be independent of distance (ρ = .27), whereas the quantity of solids shipped is related to shipping distance (ρ = .69). This finding is different from the California and Texas solids results. However, the

Figure 4.3 Frequency Histogram for Overall Sample - Massachusetts

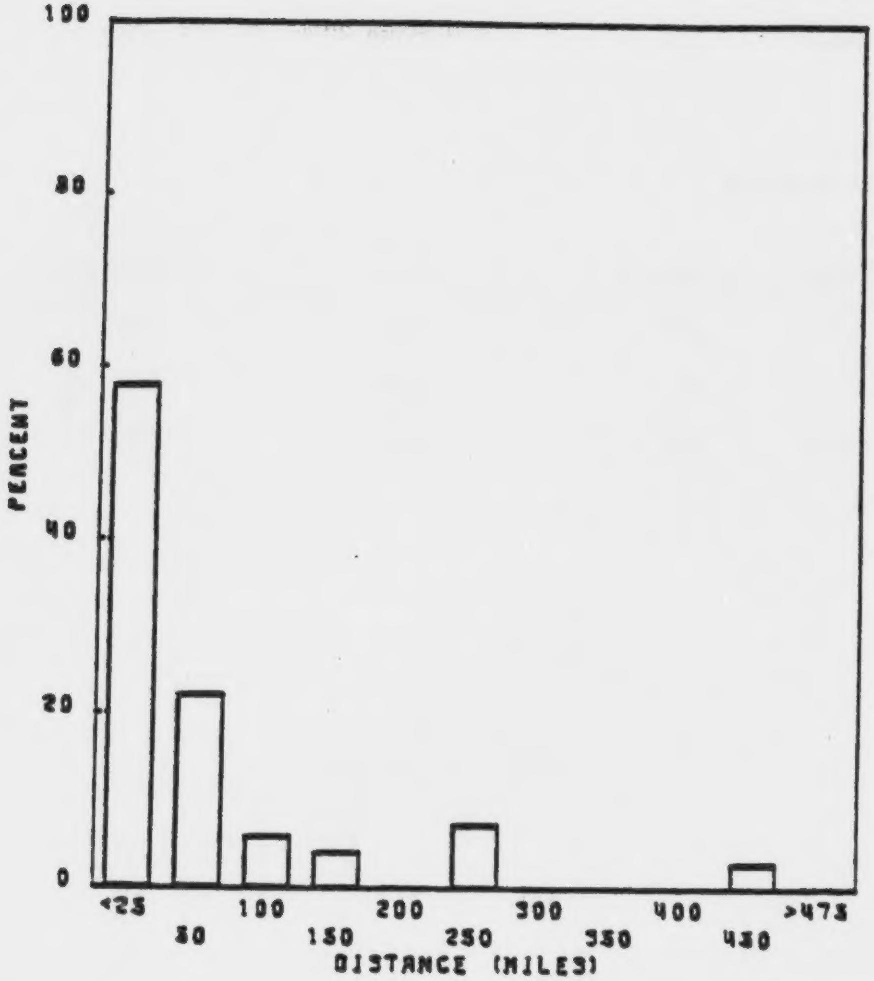


Table 4.3 Distance and Quantity Shipped - Massachusetts

Distance Shipped

Waste Type	Sample	Mean	St.Dev.
Liquid	203	65.54	112.0
Solid	30	102.7	181.2
Grand Mean	233	70.32	123.2

Quantity Shipped

Waste Type	Sample	Mean	St.Dev.
Liquid	203	1438.	1769.
Solid	30	1009.	1495.
Grand Mean	233	1383.	1739.

solids database is relatively small in Massachusetts, and the results must be interpreted accordingly.

4.2.4 New York

The New York data on hazardous waste shipments are coded in the following units:

(1) Cubic yards.

(2) Tons.

(3) Gallons.

Again, we assumed that the first two measures are for solids and the third is for liquids. These data also include several records showing that wastes were either shipped out-of-state, or orginated in other states but were disposed of in New York. We included these data in the analysis.

Figure 4.4 shows the frequency histogram of shipping distances for the overall sample and Table 4.4 displays a summary of the distances and quantities shipped by waste type. As can be seen from the table, New York has the longest mean shipping distance of the four states (128 miles), and solids have a much longer mean shipping distance than liquids. The latter observation was substantiated by the hypothesis test which was significant at the 95 percent level. This is not surprising, as the New York data includes interstate shipments, and solids are often transported long distances to landfills while liquids often travel locally to recyclers or incinerators. As in the case of the other states that were analyzed, the quantities and distances shipped are uncorrelated ($\rho = 0.17$).

Figure 4.4 Frequency Histogram for Overall Sample - New York

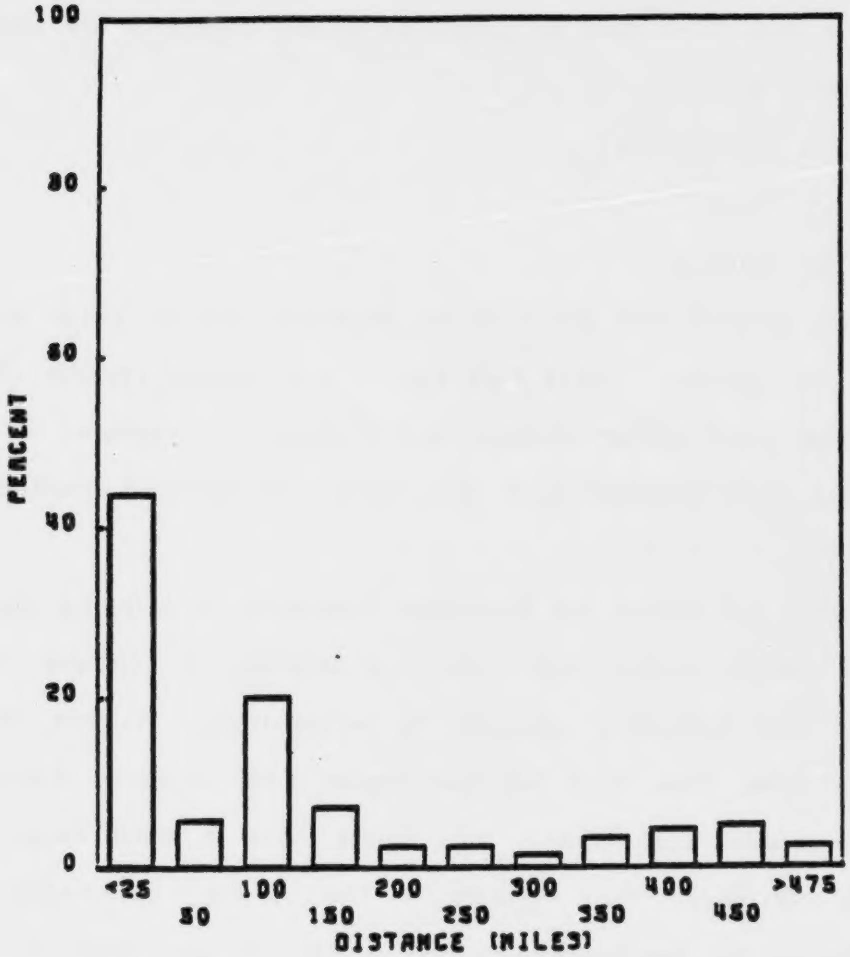


Table 4.4 Distance and Quantity Shipped - New York

Distance Shipped

Waste Type	Sample	Mean	St.Dev.
Liquid	130	94.51	119.6
Solid	63	196.8	182.4
Grand Mean	193	127.9	150.5

Quantity Shipped

Waste Type	Sample	Mean	St.Dev.
Liquid	130	2972.	2143.
Solid	63	2968.	1894.
Grand Mean	193	2971.	2060.

4.3 Implications of Pooling State Data

The results of the four state analyses varied both in terms of distances traveled and quantities shipped. This is likely due to substantial differences in the manifest system, location, size and industrial characteristics of these four states. It was also shown that there is no valid statistical argument for pooling the data from each state into an aggregate sample.

However, questions are often raised regarding general waste shipment characteristics for the United States. Although there is no basis for concluding that our sample is typical of the hazardous waste transport industry, we computed weighted averages of the shipping distances and quantities which reflect the number of annual manifests in each of the states. These weighted averages should not be misinterpreted to apply to specific hazardous waste transport scenarios in the United States.

The results appear in Table 4.5. The mean trip length for all shipments is 84.2 miles, with a mean trip length for liquids of 77.1 miles and for solids of 109.6 miles. For liquids, the mean quantity shipped is 3,171 gallons. For the solids categories, it is 2,791 gallons (11.6 tons). For both solids and liquids, the quantity shipped increases slightly with trip length, but not enough to support a statistically-significant conclusion, even at the 90 percent confidence level.

Table 4.5 Distance and Quantity Shipped - Weighted Sample

Distance Shipped

Waste Type	Sample	Mean
Liquid	499	77.1
Solid	306	109.6
Grand Mean	805	84.2

Quantity Shipped

Waste Type	Sample	Mean
Liquid	499	3171.
Solid	306	2791.
Grand Mean	805	2931.

The trip distance frequency distribution for all states, for both liquids and solids, follows an exponential distribution. This is not surprising because disposal sites are likely to be located near points of waste generation. Thus, one can represent the distance distribution as:

$$f(x) = \lambda e^{(-\lambda x)}$$

where:

x = shipping distance.

$1/\lambda$ = mean of the distribution.

4.4 Summary

Using manifest data from California, Texas, New York and Massachusetts, we examined two waste characteristics: trip distance and quantity transported per shipment. Our analyses of these data indicated that trip distance and quantity shipped vary by waste category and also vary considerably among states. This is likely due to differences in manifest systems, geographic location, size and industrial activity of each state.

We concluded that the quantity transported is independent of trip distance. Our findings do not substantiate the argument that shipments are filled closer to capacity on longer trips than shorter ones. We also found that in three of the four states, the mean shipment size for liquids is larger than for solids shipments, and that in three of the four states, the average trip distance is longer for solids shipments than for liquids shipments. Finally, we found that shipping distance, in general, can be approximated by an exponential distribution.

CHAPTER 5

INCIDENT MODELING

As defined in Chapter 2, the three types of incidents which result in the release of hazardous materials are:

(1) Container failures due to vehicular accidents enroute.

(2) Container failures occurring enroute due to causes other than vehicular accidents.

(3) Container failures at shipping terminal points.

These incidents can result from a number of failure modes. We assumed that the probability of an incident occurring depends on the particular container used in shipment. In this chapter, we describe the development of two models, the incident occurrence model and the fraction release model (the fraction release model contains two submodels, the fraction of containers failed and the fraction spilled). From these models, we derived estimates for the expected fraction released enroute and at terminal points for each of the identified container classes.

In the course of our analysis, we reviewed several studies which also examined the risk of transporting hazardous materials (for an overview discussion of this topic see TRB [6] and NCHRP[7]). In general, the methodologies for determining estimates of risk can be grouped in three broad categories: statistical estimation, fault-tree analysis and subjective estimation. Each of these techniques has advantages and disadvantages which must be evaluated in any given case. For example, the primary limitation of statistical estimation techniques is the fact that one must assume the process generating the accident/incident frequencies to be stationary. Otherwise, the estimates obtained from past data could not be used to predict future occurrences. Unlike statistical estimation methods, fault-tree analysis attempts to model the incident occurrence process in great detail. While this has great scientific appeal, there are difficulties associated with the acquisition of data for predicting basic event probabilities and the uncertainty that all significant event sequences have been considered. Nevertheless, fault-tree analysis as applied to the estimation of the risk of transporting hazardous materials has been used in several studies among which are Rhoads [8], Bercha [9] and Geffen [10]. Other studies relevant to the evaluation of risk in hazardous material transport include those of Gaylor [11], Jones [12] and NTSB [13]. The reader is referred to a comprehensive bibliography on this subject provided by Russell, et al. [14]. Of the various techniques discussed in the literature we considered statistical estimation to be the most appropriate for the present study in terms of the overall project objectives. We used the results of other researchers to check the credibility of our estimates.

5.1 Container Classification

The HAZMAT file allows the coding of up to 334 container types, 27 failure modes and 4 cause codes (see Appendices A and B). We chose cause code 3, vehicular accident, to compute the frequency of such accidents. This was done in order to avoid the possible ambiguity resulting when several failure modes appear in a given record. The other three cause codes were considered too general for this analysis and we discarded them in favor of the more detailed failure modes.

We reduced the 334 container types to 42 by eliminating those which had a low frequency of incidents (less than 10) during the analysis year (1981). We then grouped the remaining container types into 9 classes on the following basis:

(1) Similarity of physical characteristics (e.g., strength).

(2) Incident involvement.

A further analysis of the HAZMAT data revealed some records with improperly coded container capacities and others with a mismatch in the units for the quantities shipped and spilled. After we eliminated these records, there were no observations in one of the 9 classes, so we eliminated that class. In addition, there were no recorded observations for failure modes 23, 24, 25 and 26 in any class. By eliminating these 4 modes, we were left with 23 failure modes for analysis.

For each of the 8 remaining container classes we derived and plotted incident frequency and damage histograms. These histograms demonstrated that, in addition to their physical differences, the container classes differed in terms of both failure frequency and associated damage for the 23 failure modes. As a result of this step in the analysis, we identified an additional container class. The final list of container classes and the container types that comprise them is shown in Table 5.1. The frequency and damage histograms for the first 8 container classes (excluding the 'other' class) are shown in Appendix C.

5.2 Incident Occurrence Model

In order to estimate probabilities of failure from a database containing frequencies of failure, one requires a measure of the total involvement. It can be shown that if one assumes that the probability of an incident is constant along all points on a given route, then the probability of occurrence of an incident somewhere along the route is directly proportional to the length of the route. Thus, for the first two incident types (incidents enroute), the total transport distance is the total involvement. For incidents at shipment terminal points, the number of shipments is the total involvement since distance is not a factor in this case. Given the above conditions for each container class and failure mode, the limiting probability distribution for the number of incidents is a Poisson distribution. We demonstrate this result below for the number of container failures occurring enroute by failure mode "j" for a particular container class:

Let:

S be the number of shipments

$F(d)$ be the cumulative probability distribution for the shipment distances for the container class being considered

Table 5.1 Container Classification

Container Class	Container Types
1. Cylinders	278,279
2. Cans	264,266,268
3. Glass	257,274,292,295
4. Plastic	258,276,296,320
5. Fiber Boxes	69,74,260,281
6. Tanks	24,40,307,308,309,310,312,313 315,322,327,328
7. Metal Drums/Pails	91,92,95,160,161,162,282
8. Open Metal Containers	318,319
9. Other	271,273,321,326

μ_d be the mean distance shipped

N_j be the number of incidents occurring enroute by failure mode "j"

p_j be the probability of incident involvement by failure mode "j" while enroute

λ_j be the probability of incident involvement by failure mode "j" per unit distance traveled

Then for a shipment of length 'd', the probability of an incident by failure mode 'j' is $p_j = \lambda_j d$. Furthermore, the total number of shipments of distance 'd' is S dF(d).

The random variable N_j follows a binomial distribution with parameters S dF(d) and p_j:

$$P[N_j = n_j | d] = \text{binomial}[S\ dF(d), p_j]$$

The binomial distribution can be approximated by a Poisson probability mass function with parameter (p_j S dF(d)):

$$P[N_j = n_j | d] \sim \text{Poisson}[S\ dF(d) \lambda_j d]$$

Using the result that the sum of independent Poisson random variables is also a Poisson random variable with a parameter equal to the sum of the individual parameters, we obtained:

$$\begin{aligned} P[N_j = n_j] &\sim \text{Poisson}[\Sigma\ S\ dF(d)\ \lambda_j d] \\ &\sim \text{Poisson}[S\ \lambda_j \mu_d] \end{aligned}$$

The same derivation can be used for each of the other incident types.

Thus, corresponding to each container class there are a set of probability mass functions for the various incident types and failure modes given by:

Container Failure during Vehicular Accidents

$$P\{n_1 | S, \lambda, \mu_d\} = \frac{\exp(-\lambda\mu_d S)(\lambda\mu_d S)^{n_1}}{n_1!} \qquad (1)$$

Container Failures Enroute

$$P\{n_j | S, \lambda_j, \mu_d\} = \frac{\exp(-\lambda_j\mu_d S)(\lambda_j\mu_d S)^{n_j}}{n_j!} \quad j=2,23 \qquad (2)$$

Failures at Terminal Points

$$P\{m_j | S, \theta_j\} = \frac{\exp(-\theta_j S)(\theta_j S)^{m_j}}{m_j!} \quad j = 1,23 \qquad (3)$$

where S is the number of shipments, μ_d is the mean shipping distance, and the λ's and θ's are the corresponding incident rates.

We derived the estimators of λ_j and θ_j as:

$$\tilde{\lambda}_j = \frac{n_j+1}{n_1} \hat{\lambda} \qquad j = 2, \ldots, 23 \qquad (4)$$

$$\tilde{\theta}_j = \frac{m_j+1}{n_1} \hat{\lambda} \tilde{d} \qquad j = 1,2, \ldots, 23 \qquad (5)$$

where λ is an estimate of the truck accident rate in which releases occur ($\lambda = 2.8 \times 10^{-7}$ from Section 5.6), $\tilde{d}$ is an estimate of μ_d, the mean shipping distance for the container class, to be determined from the HAZMAT file (see Section 5.3), and n_j and m_j are the incident frequencies for the container class (obtained from the HAZMAT file).

Note that in equations 4 and 5, $\tilde{\lambda}_j$ and $\tilde{\theta}_j$ do not exist if $n_1 = 0$. When this occurs, the effect of the Poisson approximation in the derivation of the probability mass functions (equations 1,2, and 3) must be considered explicitly. The resulting estimators become:

$$\tilde{\lambda}_j = \frac{(n_j+1)\upsilon \exp(\upsilon N)}{\tilde{d}} E_1(\upsilon N) \qquad (6)$$

$$\tilde{\theta}_j = (m_j+1)\ \upsilon \exp(\upsilon N)\ E_1(\upsilon N) \qquad (7)$$

where N is the total number of observed incidents for the particular container class, υ is computed by:

$$N + \frac{1}{\upsilon} = \frac{1}{\hat{\lambda}\tilde{d}} \qquad (8)$$

and $E_1(z)$ is the exponential integral:

$$E_1(z) = -0.57721 - \ell nz - \sum_{n=1}^{\infty} \frac{(-1)^n z^n}{n\ n!} \qquad (9)$$

5.3 Estimating the Mean Shipment Distance

In order to compute the estimates of the incident probabilities for each container class, it was necessary to obtain an estimate of the mean shipping distance (μ_d) of all hazardous material shipments using that container class during the analysis year (1981). This information is not directly available in the HAZMAT incident file because the file contains information only for those shipments which were involved in incidents.

Below, we illustrate the derivation of an estimator for μ_d. Let "X" be a binary random variable indicating the occurrence (X=1) or non-occurrence (X=0) of an incident. Given a shipment of distance "d":

$$P\ (X=1|d) = \xi\ d, \text{ and}$$

$$P\ (X=0|d) = 1 - \xi\ d$$

where ξ is the combined incident rate (summed over all failure modes, but unique for each container class).

Also, let f(d) be the overall shipping length distribution. The conditional distribution (given an incident) is:

$$f(d|X=1) = \frac{\xi d\ f(d)}{\int \xi d\ f(d)} = \frac{d\ f(d)}{E(d)}$$

The first and second moments of this conditional distribution are:

$$\int d\ f(d|X=1) = \frac{E(d^2)}{E(d)} \qquad (10)$$

$$\int d^2\ f(d|X=1) = \frac{E(d^3)}{E(d)} \qquad (11)$$

If f(d) is assumed to follow a Gamma distribution with parameters α and β, the first three moments are:

$$E(d) = \alpha\ \beta$$

$$E(d^2) = \alpha\beta^2 + \alpha^2\beta^2$$

$$E(d^3) = (\alpha+1)(\alpha+2)\ \alpha\beta^3$$

Thus, equations 10 and 11 become:

$$E(d|X=1) = \beta\ (1 + \alpha) \tag{12}$$

$$E(d^2|X=1) = (\alpha+1)(\alpha+2)\ \beta^2 \tag{13}$$

The parameters α and β can then be determined from equations 12 and 13 by using the values of the conditional moments of the shipping distances as computed from the data in the HAZMAT file. The estimate of μ_d is then given by $\tilde{d} = \alpha\beta$. Table 5.2 summarizes the computed estimates of the mean shipping distances for seven of the container classes analyzed in this study.

5.4 Fraction Release Model

The fraction release model is comprised of two sub-models: one for the fraction of containers failed given an incident (the failure model) and the other for the fraction spilled given a failure (the spill model). We assumed that the fraction failed and fraction spilled variables are dependent on both the container type and failure mode. Using this assumption, we constructed linear models as follows:

$$F = \alpha_0 + \alpha_1 X_1 + \dots + \alpha_7 X_7 + \beta_1 Y_1 + \dots + \beta_{22} Y_{22} \tag{14}$$

$$P = \gamma_0 + \gamma_1 X_1 + \dots + \gamma_7 X_7 + \delta_1 Y_1 + \dots + \delta_{22} Y_{22} \tag{15}$$

where F and P denote the fraction failed and fraction spilled, and the Xs and Ys are binary variables denoting the container classes and failure modes, respectively. For example, an observation corresponding to container class 1 and failure mode 6 would have X_1=1 and Y_6=1; the remaining independent variables would be zero.

Table 5.2 Distance Distribution Summaries

Container Class	N	E(d|X=1)	Var(d|X=1)	α	β	$\tilde{d}$
1	60	790.38	596.55	0.7852	442.74	347.63
2	98	770.59	589.58	0.7259	446.48	324.10
3	99	942.45	651.88	1.1115	446.35	496.11
4	76	933.50	758.61	0.5344	608.37	325.11
5	79	619.20	565.73	0.2090	512.16	107.04
6	63	282.19	240.21	0.4022	201.24	80.94
7	103	858.68	637.48	0.8321	468.67	390.00

The full regression models contain 29 binary variables which define 8 container classes[7] and 23 failure codes, assuming that the interaction terms are not significant in the analysis. The regression coefficients in the models can be estimated using the spill data in the HAZMAT file. Tables 5.3 and 5.4 summarize the estimates of the dependent variables (failure and spill).[8] Table 5.5 displays the analysis of variance (ANOVA) for the full model regressions.

We then proceeded to test the hypotheses that the container classes and failure modes are significant factors affecting the fraction failed and fraction spilled. To test the hypothesis on the fraction failed, we constructed the following reduced models:

$$F = \alpha'_0 + \beta'_1 Y_1 + \dots + \beta'_{22} Y_{22}$$
$$P = \gamma'_0 + \delta'_1 Y_1 + \dots + \delta'_{22} Y_{22}$$

To test the hypothesis on the fraction spilled, the reduced models became:

$$F = \alpha''_0 + \alpha'_1 X_1 + \dots + \alpha'_7 X_7$$
$$P = \gamma''_0 + \gamma'_1 X_1 + \dots + \gamma'_7 X_7$$

Tables 5.6 and 5.7 show the ANOVA results for the two reduced models. Table 5.8 summarizes the significance tests for the container class and failure mode effects. The results demonstrate the

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[7] These models did not include container class 8.

[8] The tables include estimates from an independent regression for container class 8 (open metal containers). They do not include the estimates for container class 9 (other).

TABLE 5.3 Predicted Values of Fraction Failed by Container Class and Failure Mode

FAILURE MODE	CONTAINER CLASS							
	1	2	3	4	5	6	7	8
1	0.2966	0.2184	0.3290	0.2376	0.3218	0.7970	0.2736	0.1000
2	0.3059	0.2276	0.3382	0.2469	0.3310	0.8062	0.2828	0.2270
3	0.2555	0.1773	0.2879	0.1965	0.2806	0.7558	0.2325	0.2060
4	-	-	0.2408	0.1494	0.2336	-	0.1854	0.1250
5	-	0.1368	-	0.1560	0.2401	0.7153	0.1919	0.0400
6	-	0.2753	0.3859	0.2946	0.3787	0.8539	0.3305	0.1000
7	0.3549	0.2767	-	0.2959	0.3800	0.8552	0.3319	0.1000
8	0.2878	0.2095	0.3201	0.2288	0.3129	0.7881	0.2647	0.2960
9	0.2928	0.2146	-	0.2338	0.3179	0.7931	0.2698	0.1570
10	0.3586	0.2804	0.3910	0.2996	0.3837	0.8589	0.3356	0.2160
11	0.3884	0.3102	0.4208	0.3294	0.4135	0.8887	0.3654	0.2820
12	-	0.2894	0.4000	0.3087	0.3928	0.8680	0.3446	0.3630
13	0.3604	0.2821	0.3927	0.3014	0.3855	0.8607	0.3373	0.2730
14	0.2894	0.2112	0.3218	0.2304	0.3146	0.7898	0.2664	0.1870
15	0.2848	0.2065	-	-	0.3099	0.7851	0.2617	0.1550
16	-	0.2010	-	0.2202	0.3043	-	0.2562	0.2870
17	0.3848	0.3066	0.4172	0.3258	0.4099	0.8851	0.3618	0.1430
18	-	-	-	-	-	0.9825	-	-
19	0.4440	0.3658	0.4764	0.3850	0.4691	0.9443	0.4210	0.0540
20	-	0.1774	0.2880	0.1966	0.2807	0.7559	0.2326	0.1930
21	-	0.2805	0.3911	0.2997	0.3839	0.8591	0.3357	0.2650
22	0.2768	0.1985	0.3091	0.2178	0.3019	0.7771	0.2537	0.2540
27	-	0.6768	0.7874	-	0.7801	1.0000	0.7319	0.1000

TABLE 5.4 Predicted Values Of Fraction Spilled by Container Class and Failure Mode

FAILURE MODE	CONTAINER CLASS 1	2	3	4	5	6	7	8
1	0.4471	0.5622	0.8315	0.5843	0.3908	0.2399	0.3621	0.1000
2	0.3815	0.4966	0.7659	0.5187	0.3253	0.1743	0.2965	0.4170
3	0.4137	0.5288	0.7982	0.5510	0.3575	0.2065	0.3287	0.3510
4	-	-	0.7189	0.4717	0.2782	-	0.2495	0.5000
5	-	0.4767	-	0.4989	0.3054	0.1544	0.2766	0.5500
6	-	0.4033	0.6726	0.4254	0.2320	0.0810	0.2032	0.1000
7	0.4586	0.5737	-	0.5959	0.4024	0.2514	0.3736	0.1000
8	0.2718	0.3869	0.6562	0.4090	0.2155	0.0646	0.1868	0.1980
9	0.2075	0.3226	-	0.3447	0.1512	0.0003	0.1225	0.0960
10	0.1691	0.2842	0.5535	0.3063	0.1129	0.0003	0.0841	0.1770
11	0.2120	0.3271	0.5964	0.3492	0.1558	0.0048	0.1270	0.2200
12	-	0.4200	0.6893	0.4421	0.2487	0.0977	0.2199	0.3740
13	0.2936	0.4087	0.6780	0.4308	0.2374	0.0864	0.2086	0.4220
14	0.2789	0.3940	0.6633	0.4161	0.2227	0.0717	0.1939	0.3310
15	0.2366	0.3517	-	-	0.1804	0.0294	0.1516	0.2120
16	-	0.3622	-	0.3843	0.1909	-	0.1621	0.1540
17	0.3069	0.4220	0.6913	0.4441	0.2506	0.0997	0.2219	0.4470
18	-	-	-	-	-	0.0075	-	-
19	0.2716	0.3867	0.6560	0.4089	0.2154	0.0644	0.1866	0.6670
20	-	0.6703	0.9397	0.6925	0.4990	0.3480	0.4703	0.8580
21	-	0.5332	0.8025	0.5553	0.3619	0.2109	0.3331	0.3310
22	0.4306	0.5457	0.8150	0.5678	0.3744	0.2234	0.3456	0.4180
27	-	0.4538	0.7232	-	0.2825	0.1315	0.2537	0.1000

Table 5.5 ANOVA Table for Full Model

(a) Fraction failed

SOURCE	DF	SS	MS
Regression	30	1457.13	48.57
Residual	7774	762.87	0.10
Total	7804	2220.0	

(b) Fraction spilled

SOURCE	DF	SS	MS
Regression	30	961.78	32.06
Residual	7774	828.22	0.11
Total	7804	1790.00	

DF = degrees of freedom

SS = sum of squares

MS = mean square

Table 5.6 ANOVA Table for Reduced Model Testing for Container Class Significance

(a) Fraction failed

SOURCE	DF	SS	MS
Regression	23	1293.90	56.26
Residual	7781	926.08	0.11
Total	7804	2220.0	

(b) Fraction spilled

SOURCE	DF	SS	MS
Regression	23	841.03	32.56
Residual	7781	948.97	0.12
Total	7804	1790.00	

DF = degrees of freedom
SS = sum of squares
MS = mean square

Table 5.7 ANOVA Table for Reduced Model Testing for Failure Mode Significance

(a) Fraction failed

SOURCE	DF	SS	MS
Regression	8	1436.74	179.59
Residual	7796	783.26	0.10
Total	7804	2220.0	

(b) Fraction spilled

SOURCE	DF	SS	MS
Regression	8	908.01	113.50
Residual	7796	881.99	0.11
Total	7804	1790.00	

DF = degrees of freedom
SS = sum of squares
MS = mean square

Table 5.8 F-test Summaries

FACTOR	SUBMODEL	COMPUTED 'F'	SIGNIFICANCE
Container Class	Fraction Failed	237.54	$p < 0.01$
	Fraction Spilled	161.92	$p < 0.01$
Failure Mode	Fraction Failed	9.44	$p < 0.01$
	Fraction Spilled	22.94	$p < 0.01$

significance of both effects at the 1 percent level.

5.5 Fraction Release Estimators

Let F_j, P_j, and R_j denote the random variables fraction failed, fraction spilled and fraction released for failure mode "j", with means μ_{fj}, μ_{pj} and μ_{rj}, respectively. Thus:

$$R_j = F_j \, P_j$$

Assuming that F_j and P_j are independent:

$$\mu_{rj} = \mu_{fj} \, \mu_{pj}$$

Using r_j to denote the estimate of μ_{rj}, we obtained:

$$r_j = f_j \, p_j$$

where f_j and p_j are the mean response estimates obtained from the models in equations 14 and 15.

Recall that λ_j and θ_j denote the probabilities of incidents occurring by failure mode "j" enroute and at shipping terminal points, and that $\tilde{\lambda}_j$ and $\tilde{\theta}_j$ are their estimators. Let μ_r and μ_{rt} denote the mean fraction released per mile shipped and at terminal points, respectively. Let r and r_t denote their respective estimators. Then:

$$r = \sum_{j=2}^{23} r_j \tilde{\lambda}_j + r_1 \lambda' \qquad (16)$$

$$r_t = \sum_{j} r_j \tilde{\theta}_j \qquad (17)$$

where λ', corresponding to the failure mode 'releasing vehicular accident', is considered an input variable which need not be equivalent to the overall mean truck accident rate ($\hat{\lambda}$) used in estimating the other incident probabilities, $\tilde{\lambda}_j$ and $\tilde{\theta}_j$. In fact, depending on roadway type etc., various values of λ' can be used in computing the release fraction in equation 16.

5.6 Fraction Release Estimates

In the previous sections, we derived several estimators which are required to estimate the expected fraction released. We computed estimates for the expected fraction failed and fraction spilled as shown in Table 5.3 and 5.4. In addition, we computed estimates for the mean shipment distances for each container class (see Table 5.2). Finally, we require an estimate, $\hat{\lambda}$ (and λ'), of the releasing truck accident rate. In Chapter 6 we will discuss the determination of estimates for the truck accident rate. In computing $\hat{\lambda}$ (and λ'), however, we must account for the fact that not all truck accidents result in a release. We derived an estimate of 0.2 for the fraction of truck accidents in which a spill occurs. This was based on the following factors. First, the 1981 FRA Accident/Incident Bulletin (15) indicates that in 601 train accidents consisting of 2,770 cars carrying hazardous materials, 109 cars released. Second, previous work by Geffen [10] indicates that tank trucks involved in accidents are approximately 10 times more likely to spill than rail tank cars. These two factors yield an estimate of 0.4 which we adjusted downward to compensate for the fact that the damage threshold for an FRA reportable accident is higher than the threshold used in the HAZMAT file.

Table 5.9 summarizes the estimates of the expected fraction released both enroute and at terminal points for the container classes considered in this analysis. Note that the expected fraction released per mile shipped is expressed in terms of λ', a releasing accident rate which may vary depending on transport link characteristics. Estimates for λ' are obtained by multiplying the accident rates given in Chapter 6 for various roadway types and traffic volumes by 0.2. The aggregate accident involvement rates (releasing accidents per million truck miles) are summarized for different highway types below:

Interstate	0.13
U.S. and State	0.45
Urban	0.73
Composite	0.28

In order to evaluate our results, we compared the estimates for tanks in Table 5.9 with the results of the Bercha study [9] for tank trucks and vacuum trucks, and the PNL studies [8,10] for tank and tank-trailer combination trucks. The PNL studies report incident probabilities in a 210 km shipment of 3.68×10^{-5} and 3.57×10^{-5} for propane and gasoline carrying trucks, respectively. These values translate to an incident probability per mile of 2.8×10^{-7} which compares favorably with our estimate for the fraction released per

Table 5.9 **Estimates of Fraction Released by Container Class**

Container Class	Expected Fraction Released Per Mile Shipped	Expected Fraction Released at Terminal Points
1	$1.3 \times 10^{-6} + (.13\ \lambda')$	1.4×10^{-4}
2	$2.6 \times 10^{-6} + (.12\ \lambda')$	4.0×10^{-4}
3	$1.7 \times 10^{-6} + (.27\ \lambda')$	2.6×10^{-4}
4	$4.1 \times 10^{-6} + (.14\ \lambda')$	5.2×10^{-4}
5	$1.3 \times 10^{-6} + (.12\ \lambda')$	6.1×10^{-5}
6	$4.2 \times 10^{-8} + (.19\ \lambda')$	7.6×10^{-6}
7	$2.4 \times 10^{-6} + (.10\ \lambda')$	2.9×10^{-4}
8*	7.5×10^{-6}	1.2×10^{-3}

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*estimate associated with the release fraction during accident is not reliable.

mile of 1 x 10^{-7}. The Bercha study reports release fractions per mile of 2.02 x 10^{-7} and 1.68 x 10^{-7} for vacuum trucks and tank trucks, respectively. In addition, Bercha reports fraction release estimates during loading/unloading of 4.6 x 10^{-4} and 2.4 x 10^{-4} for vacuum trucks and tank trucks, respectively. Our results for incidents enroute are in general agreement with Bercha's. For incidents at terminal points, however, our results are two orders of magnitude lower. This apparent discrepancy could result from under-reporting of HAZMAT small spill incidents at terminals. If we remove the very small spills from the Bercha analysis, the resulting release fractions during loading/unloading for both vacuum and tank trucks become 2.4 x 10^{-5}. These are still three times higher than our estimate of 7.6 x 10^{-6}.

5.7 Errors of the Estimates

There are several sources of error which affect the release estimates in Table 5.9. These can be categorized as modeling errors and estimation errors. In this section, we are interested only in the estimation errors and their implications.

Recall that in equations 4 and 5, there are three factors to be estimated: λ, the releasing truck accident rate; μ_d, the mean shipping distance for the container class; and the incident frequency ratios. In view of the functional form of the estimators, the errors in the aforementioned factors are multiplicative. That is, a 10% error in $\hat{\lambda}$ and a 10% error in $(n_j+1)/n_1$ yields a 21% error in $\tilde{\lambda}_j$. The error in $\hat{\lambda}$, in turn, is multiplicative in the errors in the accident rate estimates and the estimates of the fraction of accidents which release. In order to gauge the total error, we looked at each of the factors individually.

The frequency ratios which we derived from the HAZMAT data could be affected by under-reporting of incidents. There is strong evidence to suggest that this occurs. However, if the under-reporting is uniform across all failure modes, our estimates are not affected. It is our view that accidents are not as likely to go unreported as are other incidents (particularly at terminals) and this would lower our estimates.

The estimates of the truck accident rates derived in this study are within the range of previously reported findings. As an average of rates representing varied highway and traffic volume conditions, the composite rate used in our analysis is lower than what was used in the PNL [8,10] and Bercha [9] studies. This again would tend to lower our estimates.

With regard to the estimate of the fraction of accidents which release, it may be argued that our estimate of 0.2 is high. For example, it has been suggested that one can use the fatality rate as a proxy for the releasing accident rate. From data reported in NHTSA [26], 8.6% of single vehicle truck accidents result in a fatality. NHTSA also reports injury rates of 24%. Thus, a factor in the range of 0.08 to 0.24 appears reasonable.

There are other factors whose errors affect the computations of the final fraction release estimates. These include sampling errors in the estimates of the fraction spilled given an accident, and errors in the estimation of the shipping distances by container types. The magnitude of these errors is given by the standard error of the estimates and is less than 20%.

As an illustration of the overall error effects, consider the possibility that we underestimated the accident rate by 25%, overestimated the fraction of releasing accidents by 100%, overestimated the shipping distance by 20% and underestimated the frequency ratio at terminals by 20%. For the above situation, the net error in the incident probability estimates would be approximately 44%.

5.8 Results and Implications

Using the HAZMAT data, we estimated the fraction of containers failed and the fraction spilled for each defined container class and by each failure mode. We also computed the probabilities of incidents occurring in two categories: enroute and at shipping terminal points. These estimates enabled us to determine the overall fraction released.

The results of our analyses indicate that in terms of their order of magnitude, the expected fractions released per mile shipped range from 10^{-8} to 10^{-6}, depending on the container class. The expected fractions released at terminal points range from 10^{-6} to 10^{-3}, depending on the container class.

Our computed estimates indicate that:

(1) The release rates for tanker trucks are much lower than for other container types.

(2) The expected amount released at terminal points is one to three orders of magnitude higher than the amount released enroute.

(3) The expected release fractions during transport are potentially as high as the release fractions at disposal sites and treatment facilities which range from 10^{-7} to 10^{-3} for routine spillage and 10^{-5} to 10^{-3} for accidental spillage [16].

CHAPTER 6

ESTIMATING THE TRUCK ACCIDENT RATE

After we derived the expected fraction release estimates per mile shipped in terms of the truck accident rate (Chapter 5), we performed an analysis of the truck accident rate data (see Chapter 3) to derive estimated accident rates for different roadway types. We defined the truck accident rate as follows:

$$y = \frac{N \times 10^6}{TADT \times L \times 365}$$

where:

y is the accident rate (accidents per million truck miles).

N is the frequency of truck accidents for the analysis year.

TADT is the average daily truck volume.

L is the length of the section over which the volume and accident data were collected.

Although the truck accident rate for a given section of road is a function of many traffic and driver related factors, the primary interest for the present analysis is in the dependence of the accident involvement rates on different highway types, and traffic and truck volume levels.

Previous research in this area includes the work of Vallette, et al. [17], ADL [18], FHWA [19], BMCS [20], Zeiszler [21], Scott and O'Day [22], Yoo [23], Smith and Wilmot [24], Meyers [25] and others (see NHTSA [26]). In several of the above studies, accurate truck exposure data was not available. In others, only one highway type was considered. The Vallette study provides reasonably accurate estimates for accident rates ranging from 0.43 to 5.24 per million truck miles for different truck and highway types. However, traffic volume levels are not considered.

6.1 Analysis

The truck accident and volume data collected from California, Texas and New Jersey (see Chapter 3) included a wide range of traffic and truck volumes, and four distinct highway types. From this 3-state database, we obtained data on the volumes and frequencies of accidents for trucks of 2-axle dual tires and larger.[9] We used this subset because it is most representative of the vehicles used to transport hazardous materials.

To test the statistical significance of any differences in accident rates for different highway and traffic volume levels, we conducted an analysis of variance (ANOVA). The analysis of the data from California and Texas was conducted as a fixed effect, three-factor (truck percentage, traffic volume and highway type), mixed design of unequal sample size. We nested the traffic volume factor (ADT) within the highway type factor because the California data seem to correspond to much higher ADT volumes than did the Texas data. Table 6.1 shows the means and standard deviations for each cell (SH = state highway, U.S. = U.S. highway and IH = interstate highway),

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[9] Excluding 2-axle pick-up and panel trucks.

Table 6.1 Cell Statistics for California and Texas

Highway Type	%Truck	ADT($x10^3$)	N	Mean	St.dev
SH	<7	0-25	15	5.623	6.456
		25-50	7	1.389	0.675
		>50	4	1.586	2.040
	>7	0-25	23	1.014	1.034
		25-50	4	0.883	0.793
		>50	4	0.554	0.317
US	<7	0-25	5	7.563	9.379
		25-50	6	2.065	3.592
		>50	6	1.590	1.544
	>7	0-25	11	1.219	0.828
		25-50	5	0.536	0.337
		>50	1	0.600	0.000
IH	<7	0-40	2	0.425	0.352
		40-80	3	1.469	1.617
		>80	11	0.951	0.549
	>7	0-40	27	0.413	0.386
		40-80	11	0.624	0.435
		>80	4	0.733	0.466

and Table 6.2 shows the group statistics. The analysis of variance in Table 6.3 demonstrates the significance of the main effects, truck percentage and ADT at the 5 percent level.

We conducted our analysis of the New Jersey data as a three-factor (truck percentage, traffic volume and number of intersections) crossed design. Our analysis of the New Jersey data also indicates the significance of the main effects at the 5 percent level. The results are summarized in Tables 6.4, 6.5 and 6.6.

6.2 Results and Implications

The analysis of the truck accident rate data yielded the following estimate for the accident involvement rates (accidents per million truck miles):

Interstates	0.65
U.S. and State Highways	2.26
Highways with interrupted flow due to intersections	3.65

These results fall within the range of previously reported estimates and demonstrate the difference in the accident rate for various highway types. Furthermore, the analysis in the previous sections shows that the truck accident rate is dependent on both the total traffic volume and the percentage of trucks in the traffic stream. These results suggest that in applying the estimates provided, cell means should be used in lieu of aggregate means if

Table 6.2 Group Statistics for California and Texas

Factor	Level	Count	Mean	St.dev.
Highway	SH	57	2.271	3.910
	US	34	2.248	4.295
	IH	58	0.632	0.584
Truck %	<7	59	2.981	4.829
	>7	90	0.740	0.728
ADT	0-25	72	2.298	4.427
	25-50	38	1.032	1.550
	>50	39	0.973	0.974

Table 6.3 ANOVA Table for New Jersey

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Statistic	Level of Significance
Main Factors					
Highway Type(H)	2	31.81	15.90	1.91	0.153
%Truck (T)	1	66.99	66.99	8.03	0.005
Nested Factor					
ADT within H	6	133.23	22.20	2.66	0.018
Interaction					
T and H	2	24.25	12.12	1.45	0.237
T and ADT within H	6	91.37	15.22	1.83	0.099
Error	131	1033.85	8.33		

Table 6.4 Cell Statistics for New Jersey

Number Intersec. per 5miles	%Truck	ADT($\times 10^3$) (veh/day)	N	Mean	St.dev
0-8	<7	0-20	10	4.709	2.489
		20-40	3	2.878	1.560
		>40	3	1.391	0.283
	>7	0-20	6	1.875	0.842
		20-40	5	1.262	1.531
		>40	2	0.457	0.034
>8	<7	0-20	2	10.28	0.022
		20-40	7	6.633	2.747
		>40	1	3.454	0.000
	>7	0-20	3	4.571	3.598
		20-40	6	2.969	0.896
		>40	4	2.406	1.176

Table 6.5 Group Statistics for New Jersey

Factor	Level	Count	Mean	St.dev.
Intersec.	0-8	29	2.703	2.266
(number/5miles)	>8	23	4.852	3.074
%Truck	<7	26	5.013	3.075
	>7	26	2.293	1.771
ADT	0-20	21	4.410	3.112
	20-40	21	3.771	2.816
	>40	10	1.817	1.184

Table 6.6 ANOVA Table for New Jersey

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Statistic	Level of Significance
Main Factors					
%TRUCK(T)	1	62.06	62.06	16.22	0.000
ADT	2	64.79	32.39	8.57	0.000
Intersections(I)	1	78.19	78.19	20.44	0.000
Interaction					
T and ADT	2	14.17	7.08	1.85	0.170
T and I	1	6.31	6.31	1.65	0.206
ADT and I	2	6.84	3.42	0.89	0.417
T and ADT and I	2	2.41	1.20	0.32	0.731
Error	40	153.02	3.82		

sufficient information is available to identify the highway type and the traffic volumes. Furthermore, if in a given situation one has available more accurate accident rate data, then the data should be used in lieu of the rates provided in this report.

For the purpose of computing the fraction release estimates in equations 16 and 17, we derived a composite truck accident rate of 1.4 accidents per million truck miles based on a weighted average of the rates previously mentioned.

CHAPTER 7

ESTIMATING THE COST OF TRANSPORTING WASTE[10]

This chapter describes how we estimated the cost of transporting hazardous wastes by truck. Briefly, our procedure was as follows. First, we reviewed the existing literature directed at estimating the cost of transporting hazardous wastes. From our review, we identified seven studies that addressed the issue of estimating the cost of transporting hazardous waste by truck. All of these studies considered this issue within the larger framework of the total cost and risk of hazardous waste treatment at a regional level.

Next, we selected the most comprehensive of these methodologies and developed a revised cost procedure using some of its assumptions and modifying others. Finally, we determined the accuracy of our costing procedure by comparing its estimated results with the actual rates charged by haulers.

7.1 Literature Review

In a report to the Environmental Council of Alberta concerning the transportation risks involved in treating hazardous waste substances, Bercha and Associates [9] addressed the costs of transporting hazardous waste by segmenting costs according to trip length:

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[10] The RCRA Risk/Cost Analysis Model uses these costing assumptions and unit costs, but uses a different accounting procedure.

Trip Length	Cost (Canadian $) Per Tonne-Kilometer	Cost (U.S. $) Per Ton-Mile
0-100 Km (62 mi)	0.120	0.176
> 100 Km (62 mi)	0.080	0.117

The Bercha analysis did not differentiate its calculated costs by truck capacity or material transported. Also, we had to make assumptions about two items that were not reported in the Bercha paper. First, we assumed that trip length corresponds to the one-way trip distance but that the costs of "deadheading" back to the point of origin are embedded in Bercha's cost estimates. Second, we assumed that trip length was segmented to reflect the decrease in per ton-mile costs that will occur with longer trips (fixed costs are distributed over a larger base).

A study by Booz, Allen and Hamilton [27] addressed transportation costs as part of an assessment of hazardous waste generation and treatement capacity. Booz-Allen assumed that all hazardous waste would be transported by either 6,000 gallon tank trucks or flatbed trucks carrying 80 drums. Their report implies that trucks would be traveling at full capacity. On the basis of interviews with facility operators, Booz-Allen posited three different "rules of thumb" for truck transport costs:

Method	Cost ($)
Flat rate per hour	\$30 - \$40
Flat rate per mile, round trip	\$1.50 - \$3.00
Fixed costs plus variable cost (usually applied to shorter trips)	\$100 - \$150 minimum charge and \$1.00 to \$1.50 per mile

It should be noted that Booz-Allen did qualify its work by stating that not all facility operators use these rules of thumb.

The Booz-Allen study does not indicate the conditions under which each costing method is most appropriate. The study also assumed that the costs for transporting waste by tank or drum are similar, and it did not recognize the expected decrease in per-mile costs associated with longer trips. Finally, the assumption that trucks travel at full capacity is not supported by analyses which have been conducted on hazardous waste shipment characteristics reported in Chapter 4. Consequently, the estimated costs are likely to be biased on the low side.

In its study of the New York State hazardous waste management program, Camp, Dresser and McKee (CDM) conducted telephone interviews with haulers operating within the state [28]. CDM obtained estimates for a 75 mile one-way trip using 4,000 gallon tank trucks. Their cost estimates (including all fees, tolls, gas and wages) ranged from $1.14 to $4.80 per truck-mile depending on distance, waste type and quantity. For their purposes, Camp, Dresser and McKee used an average cost of $1.25 - $1.50 per mile.

The importance of this study is not in the assumptions CDM adopted (which suffer from the deficiencies described previously in the Bercha and Booz-Allen discussions), but in the information obtained in conversing directly with operators. The operators themselves identified trip distance, shipment size and waste type as being important factors in determining truck transportation costs.

Transport cost was treated quite generally in a study of hazardous waste management in Massachusetts [5]. The Massachusetts Bureau of Solid Waste Disposal assumed that waste would be transported in either 80 drum trucks or 4,400 gallon tanker trucks, and that trucks only travel at full capacity. Costs were estimated at $1.00 - $3.00 per truck-mile (one-way trip), which is equivalent to $0.06 - $0.18 per ton-mile. The Massachusetts study adopted a rate of $0.12 per ton-mile. No additional insights could be gained from reviewing this costing approach. Beyond assuming that shipments are only made at full capacity, the methodology suffers from assuming that per-mile costs remain constant, irrespective of trip length and material transported.

In contrast to the variable cost structure established in the first four studies, Arthur D. Little (ADL) developed a more sophisticated approach for its assessment of hazardous waste management facilities in New England [29]. ADL recognized that the real cost of transporting wastes consists of a fixed cost (capital amortization, insurance, taxes, salaries, fringes, supervision, general and administrative) which is independent of the shipping activity and a variable cost (fuel, tires, lubrication, maintenance) which is likely to be a function of trip distance.

In developing its cost formulas, ADL assumed that a truck is in service 2,000 hours a year and, during the time that the truck is in service and on the road, the average travel speed is 40 mph. ADL further assumed that the truck operates at capacity when a shipment is made and returns empty to the point of origin. Using these and other assumptions (see Table 7.1), ADL conducted its analysis for 6,000 gallon tank trucks and stake trucks capable of carrying thirty 55-gallon drums.

Using this information, ADL derived the following cost functions:

Tanker $C_T = 0.084 + 2.45/d$

Stake truck $C_T = 0.237 + 11.01/d$

where:

C_T = cost in \$/ton-mile

d = one-way trip distance (miles)

The major advantages of ADL's approach are: 1) its detailed transportation cost components, 2) its recognition that some costs are fixed while others are variable, 3) its use of different truck types and 4) its use of unit costs which decrease as a function of trip

Table 7.1 ADL Cost Assumptions - New England

Truck Type:	**6000 Gallon Tanker Load Capacity – 25 tons**	**Stake Truck – 20 ft bed 30-55 gallon drums – 7 tons**
Capital Cost:	$55,000	$24,000
Loading and Unloading Fuel	2 hours	3 hours
Fixed Costs ($/yr)		
capital amortization 8 yrs @ 24% – 0.292	16,060	7,008
salaries & fringes @ $12.75/hr	25,500	25,500
supervision (40% of above)	10,200	10,200
insurance and taxes	4,000	4,000
	55,760	46,708
G&A @ 10%	5,576	4,671
	61,336	51,379
Operating Costs ($/mile)		
Fuel (6 mpg @ 100¢/gallon)	0.17	(9 mpg @ 100¢/gallon) 0.11
Tires and lubrication	0.05	0.03
Maintenance	0.05	0.04
	0.20	0.14
G&A @ 10%	0.02	0.01
	0.29	0.19

Source: Arthur D. Little, Inc. A Plan for Development of Hazardous Waste Management Facilities in the New England Region, Volume 2: Appendices. prepared for the New England Regional Commission, September 1979.

distance.

The drawbacks of this work are:

(1) The estimates of capital and operating costs were not validated against actual records.

(2) It was assumed that trucks operate at full capacity during transport.

(3) It was assumed that trucks are constantly in demand and available for service.

These assumptions contribute a bias toward underestimating the real transport cost per shipment.

ADL revised its 1979 costing procedure for a study of hazardous waste quantities and facility needs in Maryland [30]. The primary modifications were:

(1) Trucks were assumed to be in service 80 percent of the time.

(2) A line item for profit (5 percent of non-capital related expenses plus general and administrative expenses) was included.

(3) A roll-off container truck with capacity for eighty 55-gallon drums was included.

(4) The component costs were updated to account for inflation and other changing market conditions. For the Maryland study, ADL contacted operators and manufacturers in the U.S. to verify the plausibility of its component cost assumptions.

ADL's estimates of the cost per ton for one-way trip distances of 50 and 100 miles for tank trailers and stake trucks transporting roll-off containers appear in Tables 7.2 and 7.3. In their report, ADL described the following generalized cost formulas:

Tanker (25 tons) $C_T = 3.09 + 0.115\ d$ ($/ton)

Stake truck (18 tons) $C_T = 11.66 + 0.312\ d$ ($/ton)

However, we applied these formulas to the information in Tables 7.2 and 7.3, and obtained quite different results between the formula and table:

Distance	Truck Type	Cost/Ton Estimate in Table	Cost/Ton Estimate by Formula
50 miles	Tank	$7.91	$8.84
100 miles	Tank	$13.22	$14.59
50 miles	Stake	$12.49	$27.26
100 miles	Stake	$19.71	$42.86

These discrepancies, particularly for the stake truck, raise serious questions about the validity of the Maryland cost formulas. However, the basis for the cost estimates in Tables 7.2 and 7.3 appear to be sound.

sound

Table 7.2 ADL Pricing Procedure - Tank Trailer (Bulk Liquid - 25 Tons)

Typical Trip		
One way distance	50 miles	100 miles
Tonnage per trip	25 tons	25 tons
Loading/unloading time	2 hrs.	2 hrs.
Time on road	2.5 hrs.	5 hrs.
Total trip time	4.5 hrs.	7 hrs.
Capital Cost (1978 $)		
Power unit	$40,250	$40,250
Tank trailer	24,000	24,000
	$64,250	$64,250
Capital Related Hourly Charges		
Interest at 15%	$4.82	$4.82
Depreciation	2.86	2.86
	$7.68	$7.68
Non-Capital Related Hourly Charges		
Driver's salary	$12.50	$12.50
Supervision	2.50	2.50
Insurance	2.10	2.10
License & tax	2.00	2.00
	$19.10	$19.10
Per Mile Charges		
Fuel and oil	$0.20	$0.20
Tires, maintenance and repair	0.12	0.12
	$0.32	$0.32
Transport Costs		
Total trip time	4.5 hrs.	9 hrs.
Chargeable trip time (1.2 x total trip time)	5.4 hrs.	8.4 hrs.
Non-capital related hourly costs	$103.14	$160.44
Per mile charges	32.00	64.00
	$135.14	$224.44
G & A @ 10%	13.51	22.44
	$148.65	$246.88
Profit @ 5%	7.43	12.34
	$156.08	$259.22
Capital related hourly costs	41.72	71.32
	$197.80	$330.54
Cost per ton	$7.91	$13.22

Source: Arthur D. Little, Inc. Hazardous Waste Quantities and Facility Needs in Maryland. prepared for Hazardous Waste Facilities Siting Board and Maryland Environmental Science, August 1981.

Table 7.3 ADL Pricing Procedure - Stake Truck (Drummed Liquid, Solid; Bulk Liquid - 18 Tons)

Typical Trip		
One way distance	50 miles	100 miles
Tonnage per trip	18 tons	18 tons
Loading/unloading time	3 hrs.	3 hrs.
Time on road	2.5 hrs.	5 hrs.
Total trip time	5.5 hrs.	8 hrs.
Capital Cost (1978 $)		
Power unit	$40,250	$40,250
Tilt-frame	14.500	14,500
Roll-off container	2,800	2,800
	$57,550	$57,550
Capital Related Hourly Charges		
Interest @ 15%	$4.32	$4.32
Depreciation	2.09	2.88
	$6.41	$7.20
Non-Capital Related Hourly Charges		
Driver's salary	$12.50	$12.50
Supervision	2.50	2.50
Insurance	2.10	2.10
License and taxes	2.00	2.00
	$19.10	$19.10
Per Mile Charges		
Fuel and oil	$0.10	$0.20
Tires, maintenance and repair	0.12	0.12
	$0.32	$0.32
Transport Costs		
Total trip time	5.5 hrs.	8 hrs.
Chargeable trip time (1.2 x total trip time)	6.6 hrs.	9.6 hrs.
Non-capital related hourly costs	$126.06	$183.26
Per mile charges	32.00	64.00
	$158.06	$247.36
G & A @ 10%	15.81	24.74
	$173.87	$272.10
Profit @ 5%	8.69	13.61
	$182.56	$285.71
Capital related hourly costs	42.31	69.21
	$224.87	$354.83
Cost per ton	$12.49	$19.71

Source: Arthur D. Little, Inc. Hazardous Waste Quantities and Facility Needs in Maryland. prepared for Hazardous Waste Facilities Siting Board and Maryland Environmental Science, August 1981.

ADL's overall approach corrects for many of the first five studies' methodological problems. The major remaining problems are: 1) ADL assumed that trucks are fully loaded and 2) although it consulted operators on the component cost estimates, ADL did not examine actual cost records to determine if its total costs were representative of actual costs.

For an earlier version of the RCRA Risk/Cost Analysis Model, ICF examined the costs of transporting waste by 6,000 gallon tank trucks for one-way trip distances of 25 and 250 miles [16]. ICF assumed that on-site transportation costs were included in treatment and disposal costs (this assumption appears to be implied in the other six studies).

ICF formulated a procedure similar to that developed by ADL. However, unlike ADL, ICF did not formulate the following cost factors:

(1) Supervisory labor.
(2) Interest on capital.
(3) Insurance.
(4) Tax.
(5) General and administrative.
(6) Profit.

The ICF procedure suffers from the same deficiencies as ADL's Maryland methodology and, in addition, is not as comprehensive. For these reasons, the ICF approach appears to be less suitable for adoption than the ADL methodology.

In summary, the methodologies we reviewed fall into two major categories: variable cost models and total (fixed plus variable) cost models. The total cost models are more sophisticated in their treatment of component costs; thus, they are likely to be more representative of the real cost of operating service. Of the total cost models, ADL's Maryland model appears to be the most complete, although some deficiencies still remain.

Below, we describe a revised procedure that was developed to address these deficiencies.

7.2 Revised Procedure

We devised a costing procedure based on ADL's Maryland study cost assumptions, with the following modifications:

(1) We updated costs into 1983 terms using the consumer price index, where appropriate.

(2) We assumed average trip distances and shipment sizes based on the results of the analysis of hazardous waste shipment characteristics.

(3) We compared the revised cost formulas to actual price quotes from waste haulers in order to establish the accuracy of the revised procedure.

We estimated transport costs for 6,000 gallon tankers and 18-ton stake trucks. As in the case of the ADL study, we segmented costs into fixed and variable costs, as described in Table 7.4.

Table 7.4 Cost Assumptions for Revised Procedure

Truck Type	6000 Gallon Tanker	Stake Truck (18 Ton)
FIXED COSTS		
Capital Cost	$90,400	$81,600
Capital Amoritization 8 yrs. @ 12% = 0.201	18,170	16,402
Non-Capital Fixed Charges (1983*)		
Driver's Salary: 14.64/hr x 2000	29,280	29,280
Supervision: 2.93/hr. x 2000	5,860	5,860
Insurance: 2.10/hr. x 2000	4,200	4,200
License and Tax: 2.00/hr. x 2000	4,000	4,000
Total Capital and Fixed Charges	61,510	59,742
G + A @ 10%	6,151	5,974
Profit @ 5%	3,383	3,286
TOTAL FIXED COSTS/YR	71,044	69,002
VARIABLE COSTS ($/mile)		
Fuel and Oil	$0.23	$0.23
Tires, Main. and Repair	0.14	0.14
G + A @ 10%	0.04	0.04
Profit @ 5%	0.02	0.02
TOTAL VARIABLE COST/MILE	$0.43	$0.43

*User Consumer Price Index (CPI) figures for urban wages, the inflation rate has been as follows: 1981 = 10.4%, 1982 = 6.1%.

7.2.1 Average Cost Approach - 6,000 Gallon Tanker

Analysts often require average cost information in order to make policy decisions where detailed information on shipment characteristics is not available. This approach can be facilitated by assuming an average shipment size and trip length for a typical shipment. Below, we examine average costs for tanker transport, assuming that the tanker is carrying liquid materials.

We asssumed that: 1) the utilization rate is 80 percent (in service 1,600 hours per year), 2) time on the road is based on an average speed of 40 mph and 3) the loading/unloading time is 2 hours for each shipment. Based on the analysis of hazardous waste shipment characteristics, the weighted mean trip length is 84.2 miles and the average shipment size is 3,171 gallons, equivalent to 13.21 tons. These inputs, coupled with the information in Table 7.4, yielded the following results:

$$\text{average time per shipment} = \frac{84.2\text{x}2 \text{ miles}}{40 \text{ mph}} + 2 \text{ hrs.} = 6.21 \text{ hrs.}$$

$$\text{average trips per year} = \frac{1600 \text{ hrs}}{6.21 \text{ hrs}} = 257.65$$

$$\text{average fixed cost per trip} = \frac{71{,}044}{257.65} = \$275.74$$

$$\text{average variable cost per trip} = 0.43 \times 84.2\text{x}2 = \$72.41$$

average total cost per trip = 275.74 + 72.41 = \$348.15

$$\text{average cost per loaded mile} = \frac{348.15}{84.2} = \$4.14$$

$$\text{average cost per loaded ton-mile} = \frac{\$4.14}{13.21} = \$0.31$$

Thus, we determined that the average cost per loaded mile of tanker transport is \$4.14 and the average cost per loaded ton-mile is \$0.31.

7.2.2 Average Cost Approach - 18 Ton Stake Truck

We used the same time, distance and quantity assumptions as in the previous case, with the following exceptions:

(1) Loading/unloading time was assumed to be 3 hours.

(2) Average shipment size was assumed to be 11.63 tons.

The analysis proceeded as follows:

$$\text{average time per shipment } \frac{84.2\text{x}2 \text{ miles}}{40 \text{ mph}} + 3 \text{ hrs.} = 7.21 \text{ hrs.}$$

$$\text{average trips per year} = \frac{1{,}600 \text{ hrs}}{7.21 \text{ hrs}} = 221.9$$

$$\text{average fixed cost per trip} = \frac{\$69{,}002}{221.9} = \$310.96$$

average variable cost per trip = 0.43 x 84.2x2 = \$72.41

average total cost per trip = 310.96 + 72.41 = \$383.37

$$\text{average cost per loaded mile} = \frac{\$383.37}{84.2} = \$4.55$$

$$\text{average cost per loaded ton-mile} = \frac{\$4.55}{11.63} = \$0.39$$

The average costs per loaded mile and loaded ton-mile are larger for stake trucks than tankers. This is due to the smaller loads associated with stake trucks.

7.2.3 Deriving Cost Formulas

When details on specific shipments are available, it is extremely useful to have formulas which can be used to estimate the cost of transport. Below, we discuss how formulas were derived for tankers and stake trucks.

After defining F as annual fixed cost, X as one-way shipment length (miles), Y as shipment size (tons) and Z as loading/unloading time (hrs), we expressed the average cost per loaded mile as:

$$\text{clm}(\$/\text{loaded mile}) = \frac{F}{(1600/(.05X+Z))} \quad \frac{1}{2X} + (0.43 \text{x} 2)$$

For *tankers:* F = \$71,044 and Z = 2. Therefore, the cost per loaded mile for *tankers* is:

$$\text{clm}_{\text{tanker}} \ (\$/\text{loaded mile}) = 3.08 + \frac{88.8}{X} \qquad (18)$$

The cost per loaded ton-mile (ctm) for *tankers* is:

$$\text{cltm}_{\text{tanker}} \text{ (\$/loaded ton-mile)} = \frac{3.08}{Y} + \frac{88.8}{XY} \tag{19}$$

For *stake trucks*, F = \$69,002 and Z = 3.

The cost per loaded mile for *stake trucks* is:

$$\text{clm}_{\text{stake}} \text{ (\$/loaded mile)} = 3.02 + \frac{129.38}{X} \tag{20}$$

The cost per loaded ton-mile for *stake trucks* is:

$$\text{cltm}_{\text{stake}} \text{ (\$/loaded ton-mile)} = \frac{3.02}{Y} + \frac{129.38}{XY} \tag{21}$$

7.3 Comparison with Actual Charges

To determine the accuracy of our costing procedure, we compared the cost estimates using the revised costing procedure with actual rates charged by haulers. We obtained the information on actual rates from a study of hazardous waste haulers' transportation costs conducted by Temple, Barker and Sloane, Inc. (TBS) in May 1983 [31].

In their cost study of drum and bulk waste transport activities, TBS contacted a number of companies involved in the treatment, disposal and transportation of hazardous wastes. TBS experienced considerable difficulty in obtaining cost information that could be used to compare one operation directly to another. In fact, companies varied in terms of type of truck, vehicle capacity, area of service, average hauling distance, quoted rates and the units to establish rates. Nevertheless, TBS attempted to establish a uniform scale by converting all rates to $/loaded mile.

For 5,000-6,000 gallon tankers, the quoted rates ranged from $2.75 - $4.50 per loaded mile, with an average of $3.40. Using the average cost approach, we estimated the average cost per loaded mile to be $4.14, which is toward the upper bound of what most shippers are charging. However, the lower costs in the quoted range were for one-way trips of 200-300 miles; this distance is well above the average one-way trip distance (84.2 miles) used in the average cost procedure. Using the derived cost formula for tankers with a one-way trip distance of 300 miles, we estimated the average cost to be $3.38 per loaded mile, which is consistent with the amount operators reported that they charge for a 300 mile one-way trip.

For stake trucks capable of handling 70 to 88 drums, the TBS study reported that the rate per loaded mile ranged from $2.10 to $4.00, with an average of $3.30. The average cost approach yielded an estimate of $4.55. Again, the lower rates in the TBS study were associated with longer trip lengths (200 to 300 miles) than we used. Using the derived cost formula for stake trucks, the estimated cost per loaded mile for a 300 mile one-way shipment is $3.45, which compares rather favorably with the reported rates.

In conclusion, the derived cost formulas appear to be representative of the hazardous waste transport industry quoted rates, particularly for the long-haul market. The use of the average cost figures, however, should be treated more carefully, and should only be employed when information is not available on shipment size and trip distance.

7.4 Summary

We reviewed seven methods for estimating the cost of transporting hazardous waste by truck. The results varied from gross estimates of the unit cost of transport to more sophisticated derivations of cost based on fixed and variable components. We noted several deficiencies in these methods, particularly in the assumptions relating to shipment characteristics and the failure to compare results to the actual rates charged by waste haulers.

We then developed a revised costing procedure which was designed to overcome these deficiencies. Using this procedure, we derived new cost formulas for estimating the cost of wastes transported by tanker and stake truck. The cost estimates based on these formulas compared quite favorably with actual industry quotes. Consequently, we feel that these formulas can be adopted for use in policy analysis.

CHAPTER 8

MODEL APPLICATION AND CONCLUDING REMARKS

Below, we present two case studies which illustrate the application of the fraction release and cost models. The case studies represent two different scenarios and demonstrate the flexibility of the models. The results of the case studies are summarized in Table 8.1.

8.1 Scenario 1

From a policy standpoint, it is often meaningful to obtain estimates of the fraction released for a large number of shipments. Thus, we posed the following problem: Suppose 10^6 gallons of liquid waste are shipped over a highway network by tanker truck. No other information is available. What are the expected releases and costs of transporting this material?

8.1.1 Release Computation

From Table 4.5 we used the mean distance for shipping liquids of 77.1 miles. Because no information was available on the nature of the highway network, we used the appropriate mean (releasing) accident rate of $\lambda' = 2.8 \times 10^{-7}$ accidents per truck mile from Chapter 5. The expected amount released enroute was obtained using the fraction released from Table 5.9 as:

Table 8.1 Summary of Results of Case Study

	Scenario	Scenario 2
Quantity Shipped (gals.)	10^6	200 x 55
Distance Shipped (miles)	77.1	100
Quantity per Vehicle (gals.)	3171	2791
Average Number of Shipments	315.4	3.94
Truck Accident Rate ($\times 10^{-7}$)	0.28	.13
Expected Release Enroute (gals.)	7.34	2.65
Expected Release Handling (gals.)	7.6	3.19
Total Release (gals.)	14.94	5.84
Total Release (%)	0.0015	0.053
Cost per Ton-mile ($)	0.32	0.37
Number of Ton-miles	1018.5	1160.0
Cost per Shipment ($)	325.92	429.20
Total Transport Cost ($)	102,795.17	1691.05

$$E(\text{released enroute}) = (4.2\times10^{-8} + 0.19\times2.8\times10^{-7}) \times 10^{6} \times 77.1$$
$$= 7.34 \text{ gallons}$$

Similarly, the expected amount released at terminal points is:

$$E\ (\text{release at terminals}) = 7.6\times10^{-6} \times 10^{6}$$
$$= 7.6 \text{ gallons}$$

Total expected release = 14.94 gallons

8.1.2 Cost Analysis

From Table 4.5, the weighted mean shipment size for liquids is 3171 gallons, which is equivalent to 13.21 tons. Using equation 19, the cost per ton-mile is:

$$\text{cltm}_{\text{tanker}}\ (\$/\text{loaded ton-mile}) = \frac{3.08}{13.21} + \frac{88.8}{(13.21)(77.1)} = 0.32$$

Number of ton-miles per shipment = 13.21 x 77.1 = 1018.5

Cost per shipment = 1018.5 x 0.32 = $325.92

Average number of shipments = $10^6/3171$ = 315.4

Total Cost = 315.4 x 325.92 = $102,795.17

8.2 Scenario 2

On a more disaggregated level, it is often useful to obtain estimates of the anticipated fraction released for point-to-point shipments. Thus, we formulated a problem which would be characteristic of this class: Suppose 200 55-gallon drums are being shipped a distance of 100 miles on Interstate highways. The ADT and truck percentages on the highways are unknown. What are the expected releases and costs involved?

8.2.1 Release Computation

From Chapter 5, we obtained the accident rate for Interstates as $\lambda' = 0.13 \times 10^{-6}$ accidents per truck mile. The expected amount released enroute was obtained using the fraction released from Table 5.9 as:

$$E\ (\text{release enroute}) = (2.4\times10^{-6} + 0.10\times0.13\times10^{-6}) \times 100 \times 200 \times 55$$
$$= 2.65 \text{ gallons}$$

$$E\ (\text{release at terminals}) = 2.9\times10^{-4} \times 200 \times 55$$
$$= 3.19 \text{ gallons}$$

Total expected release = 5.84 gallons

8.2.2 Cost Analysis

The average load carried by stake trucks is 2791 gallons, which is equivalent to 11.6 tons. The quantity being shipped is 11,000 gallons which is equivalent to 45.83 tons. Using equation 21, the cost per loaded ton-mile is:

$$\text{cltm}_{\text{stake}} \text{ (\$/loaded ton-mile)} = \frac{3.02}{11.6} + \frac{129.38}{(100)(11.6)} = 0.37$$

Number of ton-miles per shipment = 11.6 x 100 = 1160

Cost per shipment = 1160 x 0.37 = $429.20

Average number of shipments = 3.94

Total Cost = 3.94 x 429.20 = $1,691.05

8.3 Concluding Remarks

This project has addressed the potential risks and costs of transporting hazardous wastes by truck. In the course of conducting this study, we drew several conclusions that are useful for policy analysis. Below, we briefly discuss our conclusions.

A trip profile analysis conducted on data from several states indicated that, on average, wastes are shipped less than 100 miles from their generation to their disposal sites. The average trip length is lower for liquids than for solids. Generally speaking, the mean quantity shipped is independent of shipping distance.

In assessing truck transport risk, it is important to distinguish between two kinds of incidents that result in spills. For one class of incidents, the probability of occurrence is a function of the distance traveled; for the other, the occurrence probability for a particular shipment is fixed. We computed expected fraction release estimates for both kinds of incidents.

The costs of transporting hazardous wastes by truck can be reasonably approximated using the formulas derived in this study. These cost formulas compare quite favorably with actual industry quotes.

The individual and collective results of the entire analysis are applicable at many levels of aggregation. Using this study's models and cost formulas, it is possible to obtain broad estimates of expected releases and transport costs, as well as estimates of the risks and costs involved in individual shipments.

Perhaps the most important result of this study is that the risk of transporting hazardous wastes by truck appears to be as large as the potential risks at treatment and disposal sites. In fact, for some W-E-T combinations, transport may be a potentially more dangerous activity. As a result, policymakers should give careful consideration to the relative risks involved in the treatment, transport and disposal of hazardous wastes.

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APPENDIX A

LIST OF CONTAINER TYPES

CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

APBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
1	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
2	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
3	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
4	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
5	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
6	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
7	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
8	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
9	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
10	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
11	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
12	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
13	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
14	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
15	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
16	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
17	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
18	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
19	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
20	YES	—	—	YES	TANK CAR	YES		179.100	Pressure
21	YES	—	—	YES	TANK CAR	YES		179.100	Pressure
22	YES	—	—	YES	TANK CAR	YES		179.100	Pressure
23	YES	—	—	YES	TANK CAR	YES		179.100	Pressure
24	YES	—	—	YES	TANK CAR	YES		179.100	Pressure
25	YES	—	—	YES	TANK CAR	YES		179.300	Multi-unit
26	YES	—	—	YES	TANK CAR	YES		179.300	Multi-unit
27	YES	—	—	YES	TANK CAR	YES		179.300	Multi-unit
28	YES	—	—	YES	TANK CAR	YES		179.300	Multi-unit
29	YES	—	—	YES	TANK CAR	YES		179.500	High pressure
30	YES	—	—	YES	TANK CAR	YES		179.100	Pressure
31	YES	—	—	YES	TANK CAR	YES		179.100	Pressure
32	—	YES	YES	—	BARREL/KEG WOOD	NO	19740515	171.14	Wooden barrels and kegs (tight)
33	—	YES	YES	—	BARREL/KEG WOOD	YES		178.156	Wooden barrels and kegs (tight)
34	—	YES	YES	—	BARREL/KEG WOOD	NO	19740515	171.14	Wooden barrels and kegs (tight)
35	YES	—	—	YES	TANK CAR	YES		179.300	Multi-unit
36	YES	—	—	YES	TANK CAR	YES		179.300	Multi-unit
37	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
38	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
39	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
40	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
41	YES	—	—	YES	TANK CAR	NO	19771231	179.100	Pressure
42	YES	—	—	YES	TANK CAR	NO	19771231	179.100	Pressure
43	YES	—	—	YES	TANK CAR	NO	19771231	179.100	Pressure
44	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure
45	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure

* See codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTWO.DMS	CONT2

CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

ABBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
46	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure
47	YES	—	—	YES	TANK CAR	YES		179.100 23	Pressure
48	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure
49	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure
50	YES	—	—	YES	TANK CAR CRYO	YES		179.400	Liquified hydrogen
51	YES	—	—	YES	TANK CAR CRYO	YES		179.400	Liquified hydrogen
52	YES	—	—	YES	TANK CAR	YES		179.400	Liquified hydrogen
53	YES	—	—	YES	TANK CAR CRYO	YES		179.400	Liquified hydrogen
54	YES	—	—	YES	TANK CAR	YES		179.400	Liquified hydrogen
55	YES	—	—	YES	TANK CAR	YES		179.400	Liquified hydrogen
56	YES	—	—	YES	TANK CAR	NO	19771231	179.100	Pressure
57	YES	—	—	YES	TANK CAR	NO	19771231	179.100	Pressure
58	YES	—	—	YES	TANK CAR	NO	19771231	179.100	Pressure
59	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure
60	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure
61	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure
62	YES	—	—	YES	TANK CAR	YES		179.100 23	Pressure
63	YES	—	—	YES	TANK CAR	YES		179.105 2	Pressure
64	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
65	YES	—	—	YES	TANK CAR	YES		179.200	Non-pressure
66	—	YES	YES	—	BARREL/KEG WOOD	NO	19740515	171.14	Wooden barrels and kegs (slack)
67	—	YES	YES	—	BARREL/KEG WOOD	NO	19740515	171.14	Wooden barrels and kegs (slack)
68	—	YES	YES	—	BOX FIBER	YES		178.210	Boxes NRC*
69	—	YES	YES	—	BOX FIBER	YES		178.205	Boxes
70	—	YES	YES	—	BOX FIBER	YES		178.206	Boxes
71	—	YES	YES	—	BOX FIBER	YES		178.207	Boxes
72	—	YES	YES	—	BOX FIBER	YES		178.208	Boxes
73	—	YES	YES	—	BOX FIBER	YES		178.209	Boxes
74	—	YES	YES	—	BOX FIBER	YES		178.211	Boxes NRC*
75	—	YES	—	—	BOX FIBER	YES		178.212	Paper faced expanded polystyrene NRC*
76	YES	—	—	—	KEG METAL	YES		176.140	Metal kegs
77	YES	—	—	—	DRUM METAL	YES		178.141	Metal drums
78	—	YES	—	—	BOX WOOD	YES		178.165	Nailed
79	—	YES	—	—	BOX WOOD	YES		178.168	Nailed
80	—	YES	—	—	BOX WOOD	YES		178.169	Nailed
81	—	YES	—	—	BOX WOOD	YES		178.170	Nailed
82	—	YES	—	—	BOX WOOD	YES		178.171	Nailed
83	—	YES	—	—	BOX WOOD	YES		178.172	Fiberboard lined
84	—	YES	—	—	BOX WOOD	YES		178.176	Boxes
85	—	YES	—	—	BOX WOOD	YES		178.177	Metal lined
86	—	YES	—	—	BOX WOOD	YES		178.182	Glued plywood or wooden box
87	—	YES	—	—	BOX WOOD	YES		178.181	Wooden boxes for two five-gallon cans
88	—	YES	—	—	BOX WOOD	YES		178.185	Plywood or wooden boxes, wirebound
89	—	YES	—	—	BOX WOOD	YES		178.186	Wooden boxes, wirebound
90	—	YES	—	—	BOX WOOD	YES		178.187	Wooden wirebound overwrap

* See codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTJO.DMS	CONT2

CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

ABBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
91	YES	—	YES	—	DRUM METAL	YES		178.115	Steel STC* RHA*
92	YES	—	—	—	DRUM METAL	YES		178.116	Steel STC* RHNA*
93	YES	—	YES	—	DRUM METAL	YES		173.28	Reconditioned 17E (closed head), converted t: 17H (open head) STC* RHR*
94	YES	—	—	—	DRUM METAL	YES		178.117	Steel STC* RHNA*
95	YES	—	YES	—	DRUM METAL	YES		178.118	Steel STC* RHR*
96	YES	—	—	—	DRUM METAL	YES		178.119	Steel barrels or drums STC* RHNA*
97	—	YES	—	—	BOX WOOD	YES		178.193	Wooden kits
98	—	YES	—	—	BOX WOOD	YES		178.190	Wooden boxes, plywood, cleated
99	—	YES	—	—	BOX WOOD	YES		178.191	Wooden boxes, plywood, nailed
100	YES	—	—	—	CARBOY	YES		178.1	Boxed
101	YES	—	—	—	CARBOY	NO	19790511	178.2	Boxed lead
102	YES	—	—	—	CARBOY	NO	19790511	178.3	In kegs
103	YES	—	—	—	CARBOY	YES		178.4	Boxed glass
104	YES	—	—	—	CARBOY	NO	19790511	178.7	Glass, in plywood drums
105	YES	—	—	—	CARBOY	YES		178.6	Glass, in plywood drums STC*
106	YES	—	—	—	CARBOY	YES		[illegible]	Polyethylene, in metal crates
107	YES	—	—	—	CARBOY	YES		178.14	Glass, cushioned with expandable polystyrene in wooden wirebound box
108	YES	—	—	—	CARBOY	YES		178.17	Glass with expanded polystyrene overpack
109	YES	—	—	—	CARBOY	YES		178.5	Boxed, 5 to 6 1/2 gallons for export only STC*
110	—	YES	—	—	RAM CONTAINER	YES		178.120	Phenolic-foam insulated, metal overpack
111	—	YES	—	—	RAM CONTAINER	YES		178.194	Wooden protective jacket
112	YES	—	YES	—	DRUM NON-METAL	YES		178.224	Fiber drum
113	—	YES	—	—	DRUM NON-METAL	YES		178.225	Fiber drum overpack for inside plastic container
114	—	YES	—	—	RAM CONTAINER	YES		178.121	Fire and shock resistant, phenolic-foam insulated, metal overpack
115	—	YES	—	—	RAM CONTAINER	YES		178.195	Wooden protective overpack
116	—	YES	—	—	DRUM NON-METAL	YES		178.196	Wooden drums, plywood
117	—	YES	—	—	DRUM NON-METAL	YES		178.197	Wooden drums, plywood
118	—	YES	—	—	DRUM NON-METAL	YES		178.198	Plywood drum for plastic inside container
119	—	YES	YES	—	BOX FIBER	YES		178.214	Fiberboard boxes
120	—	YES	YES	—	BOX FIBER	YES		178.218	Special cylindrical fiberboard box for high explosives
121	—	YES	YES	—	BOX FIBER	YES		178.219	Fiberboard boxes
122	YES	—	—	YES	TANK	NO		173.301h	Steel cylinder, seamless, maximum size 120 pounds water capacity
123	YES	—	—	YES	TANK	NO		173.301h	Steel cylinder, seamless, maximum size 220 pounds water capacity
124	YES	—	—	—	CARBOY	NO	19790511	178.8	Metal-Jacketed
125	YES	—	—	—	CARBOY	NO	19790511	178.9	Metal-Jacketed
126	—	YES	YES	—	TUBE	YES		178.26	Mailing tube
127	YES	—	—	—	INSIDE CONTAIN	YES		178.20	Metal cans, pails and kits

* See codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTWO.DMS	CONT2

CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

ABBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
128	YES	—	—	—	INSIDE CONTAIN	YES		178.22	Corrugated fiberboard cartons
129	YES	—	—	—	INSIDE CONTAIN	YES		178.23	Duplex paper bags
130	YES	—	—	—	INSIDE CONTAIN	YES		178.24a	Polyethylene bottle
131	YES	—	—	—	INSIDE CONTAIN	YES		178.25	Metal containers and liners
132	YES	—	—	—	INSIDE CONTAIN	YES		178.26	Fiber cans and boxes
133	YES	—	—	—	INSIDE CONTAIN	YES		178.28	Waterproof paper bags for linings
134	YES	—	—	—	INSIDE CONTAIN	YES		178.29	Paper bags for linings
135	YES	—	—	—	INSIDE CONTAIN	YES		178.30	Lining for boxes
136	YES	—	—	—	INSIDE CONTAIN	YES		178.31	Waterproof paper lining
137	YES	—	—	—	INSIDE CONTAIN	YES		178.32	Metal cans
138	YES	—	—	—	INSIDE CONTAIN	YES		178.33	Non-refillable metal containers
139	YES	—	—	—	INSIDE CONTAIN	YES		178.33a	Non-refillable metal containers
140	YES	—	—	—	INSIDE CONTAIN	YES		178.34	Metal tubes for radioactive materials
141	YES	—	—	—	INSIDE CONTAIN	YES		178.35	Polyethylene containers RHNA*
142	YES	—	—	—	INSIDE CONTAIN	YES		178.35a	Polyethylene containers RHNA*
143	YES	—	—	—	INSIDE CONTAIN	YES		178.21	Polyethylene containers
144	YES	—	—	—	INSIDE CONTAIN	YES		178.27	Polyethylene containers
145	YES	—	—	—	INSIDE CONTAIN	YES		178.24	Polyethylene containers over one gallon capacity RHNA*
146	YES	—	—	—	CYLINDER	NO		173.301h	Steel cylinder, seamless
147	YES	—	—	—	JUG	NO	19790511	178.15	Jugs in tubs
148	—	YES	YES	—	BOX METAL	YES		178.146	Metal cases, riveted or lock-seamed
149	—	YES	YES	—	BOX METAL	YES		178.147	Metal cases, welded or riveted
150	—	YES	YES	—	BOX METAL	YES		178.148	Metal trunks
151	—	YES	YES	—	BOX METAL	YES		178.149	Metal boxes
152	YES	—	—	YES	TANK	NO		173.301h	Steel cylinder, seamless, maximum size 120 pounds water capacity
153	—	YES	—	—	OTHER	YES		178.150	Polystyrene cases
154	YES	—	—	—	DRUM NON-METAL	YES		178.19	Reusable molded polyethylene container without overpack RHNA*
155	YES	—	—	—	CARBOY	NO	19790511	178.12	Aluminum carboys
156	YES	—	—	—	DRUM NON-METAL	YES		178.16	Non-reusable molded polyethylene drum for use without overpack RHR*
157	YES	—	YES	—	BAG CLOTH	YES		178.230	Lined cloth (triplex)
158	YES	—	YES	—	BAG CLOTH	YES		178.233	Burlap, lined
159	YES	—	YES	—	BAG CLOTH	YES		178.234	Burlap, paper lined
160	—	YES	YES	—	DRUM METAL	YES		178.131	Drums STC* RHR*
161	YES	—	—	—	DRUM METAL	YES		178.132	Drums STC* RHNA*
162	—	YES	YES	—	DRUM METAL	YES		178.135	Drums NRC* RHR*
163	YES	—	—	—	DRUM METAL	YES		178.137	Drums NRC* RHNA*
164	—	YES	YES	—	DRUM METAL	YES		178.130	Drums STC* RHA*
165	—	YES	—	—	DRUM METAL	YES		178.134	Steel overpack for inside plastic container NRC*
166	—	YES	—	—	DRUM METAL	YES		178.133	Steel drums with polyethylene liner
167	YES	—	—	YES	TANK	NO		173.301h	Steel cylinder, seamless, maximum size 5 pounds water capacity

* See codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTWO.DMS	CONT2

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CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

ABBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
168	YES	—	—	—	CYLINDER	YES		178.65	Non-reusable (non-refillable) cylinders NRC
169	YES	—	—	YES	CYLINDER BULK	YES		178.36	Seamless steel
170	YES	—	—	—	CYLINDER	YES		178.43	Seamless steel
171	YES	—	—	—	CYLINDER	YES		178.37	Seamless steel, made of definitely prescrib steels
172	YES	—	—	YES	CYLINDER TRL	YES		178.37	Seamless steel, made of definitely prescrib steels over 1000 pounds water volume
173	YES	—	—	—	CYLINDER	YES		178.46	Seamless cylinder made of definitely prescribed aluminum alloys
174	YES	—	—	YES	CYLINDER TRL	YES		178.36	Seamless steel, over 1000 pounds water volu
175	YES	—	—	—	CYLINDER	YES		178.38	Seamless steel
176	YES	—	—	—	CYLINDER	YES		178.39	Seamless nickel
177	YES	—	—	—	CYLINDER	YES		178.40	Seamless steel
178	YES	—	—	—	CYLINDER	YES		178.41	Seamless steel
179	YES	—	—	—	CYLINDER	YES		178.42	Seamless steel
180	YES	—	—	—	CYLINDER	YES		178.44	Inside containers, seamless steel for A/C* use
181	YES	—	—	—	CYLINDER	YES		178.45	Seamless steel
182	YES	—	—	—	CYLINDER	YES		178.48	Forge welded steel
183	YES	—	—	—	CYLINDER	NO			Non-refillable metal containers
184	YES	—	—	—	CYLINDER	NO			Non-refillable metal containers
185	YES	—	—	—	DRUM METAL	NO	19301001	173.268c 1	Aluminum drum
186	YES	—	—	—	DRUM METAL	YES		178.107	Drums
187	YES	—	—	—	DRUM METAL	YES		178.108	Barrels or drums
188	YES	—	—	—	DRUM METAL	YES		178.109	Drums
189	YES	—	—	—	DRUM METAL	YES		178.136	Drums STC*
190	YES	—	—	—	DRUM METAL	YES		178.110	Barrels or drums RHR*
191	YES	—	—	—	DRUM METAL	YES		178.111	Drums
192	YES	—	—	—	DRUM METAL	YES		178.112	Drums RHNA*
193	YES	—	—	—	DRUM NON-METAL	NO	19790511	178.18	Rubber drums
194	YES	—	YES	—	BAG PAPER	YES		178.236	Paper bags
195	YES	—	YES	—	BAG PAPER	YES		178.237	Paper bags
196	YES	—	YES	—	BAG PAPER	YES		178.238	Paper bags
197	YES	—	YES	—	BAG PAPER	YES		178.239	Paper bags
198	YES	—	YES	—	BAG PLASTIC	YES		178.241	All plastic bag
199	YES	—	YES	—	BAG CLOTH	YES		178.240	Bags, cloth and paper, lined
200	YES	—	—	—	CYLINDER	YES		178.49	Forge welded steel
201	YES	—	—	—	CYLINDER	YES		178.56	Welded steel
202	YES	—	—	—	CYLINDER	YES		178.50	Welded and brazed steel
203	YES	—	—	—	CYLINDER	YES		178.55	Welded and brazed
204	YES	—	—	—	CYLINDER	YES		178.54	Welded or welded and brazed
205	YES	—	—	—	CYLINDER	NO		173.304d 3	Cylinder without longitudinal seam for pressures of 150 to 500 pounds psi
206	YES	—	—	—	CYLINDER	YES		178.51	Welded or brazed steel, made of definitely prescribed steels

* See codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTWC.DMS	CONT2

CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

ABBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
207	YES	—	—	—	CYLINDER	YES		178.61	Welded steel
208	YES	—	—	—	CYLINDER	YES		178.52	Welded and brazed steel
209	YES	—	—	—	CYLINDER	YES		178.53	Inside containers, welded steel
210	YES	—	—	—	CYLINDER	YES		178.58	Inside containers, welded steel for A/C*
211	YES	—	—	—	CYLINDER	YES		178.47	Inside containers, welded stainless stee
212	YES	—	—	—	CYLINDER	YES		178.68	Welded aluminum
213	YES	—	—	—	CYLINDER	YES		178.57	Welded, insulated
214	YES	—	YES	—	DRUM METAL	YES		178.80	Steel barrels or drums RHA*
215	YES	—	—	YES	TANK	NO		173.32c	Steel portable tank
216	YES	—	—	YES	TANK	YES		178.245	Steel
217	YES	—	—	YES	TANK	NO		173.32b	Steel portable tank
218	YES	—	—	YES	TANK	NO		173.32d	Aluminum or magnesium portable tanks
219	YES	—	—	YES	TANK	NO		173.32d	Cylindrical aluminum portable tank
220	—	YES	—	—	RAM CONTAINER	NO	19750331	173.395A 2	Metal encased, uranium or lead shielded container for radioactive materials
221	YES	—	—	YES	TANK	YES		178.252	Metal
222	YES	—	—	YES	TANK	YES		178.253	Metal
223	YES	—	—	—	DRUM METAL	YES		178.81	Steel barrels or drums RHNA*
224	YES	—	YES	—	DRUM METAL	YES		178.82	Steel barrels or drums RHA*
225	YES	—	—	—	DRUM METAL	YES		178.83	Steel barrels or drums RHNA*
226	YES	—	YES	—	DRUM METAL	YES		178.84	Steel barrels or drums, lined RHA*
227	YES	—	—	—	DRUM METAL	YES		178.85	Steel drums RHNA*
228	YES	—	—	—	DRUM METAL	YES		178.87	Steel barrels or drums, lead lined RHNA*
229	YES	—	—	—	DRUM METAL	YES		178.88	Nickel barrels or drums RHNA*
230	YES	—	—	—	DRUM METAL	YES		178.89	Steel barrels or drums RHNA*
231	YES	—	—	—	DRUM METAL	YES		178.90	Monel drums
232	YES	—	—	—	DRUM METAL	YES		178.92	Lagged steel drums RHNA*
233	YES	—	—	—	DRUM METAL	YES		178.91	Steel drums, aluminum lined RHNA*
234	YES	—	—	YES	TANK	YES		178.255	Steel
235	YES	—	YES	—	DRUM METAL	YES		178.97	Steel barrels or drums RHA*
236	YES	—	YES	—	DRUM METAL	YES		178.98	Steel barrels or drums RHA*
237	YES	—	YES	—	DRUM METAL	YES		178.99	Steel barrels or drums RHA*
238	—	YES	—	—	DRUM METAL	YES		178.102	Cylindrical steel overpack, straight sides for inside plastic containers
239	YES	—	YES	—	DRUM METAL	YES		178.100	Steel barrels or drums RHA*
240	YES	—	YES	—	DRUM METAL	YES		178.101	Steel barrels or drums RHA*
241	—	YES	—	—	RAM CONTAINER	YES		178.103	Metal packaging
242	—	YES	—	—	RAM CONTAINER	YES		178.104	Metal packaging
243	—	YES	—	—	RAM CONTAINER	YES		178.350	General packaging, for type A radioactive materials
244	YES	—	—	—	CYLINDER	YES		178.59	Steel for acetylene
245	YES	—	—	—	CYLINDER	YES		178.60	Steel for acetylene
246	YES	—	—	—	CYLINDER	YES			Non-refillable metal containers
247	YES	—	YES	—	BAG CLOTH	YES			Cloth or burlap bag (cont1 for solid materials)

* see codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTWO.DMS	CONT2

CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

ABBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
248	YES	—	YES	—	BAG PLASTIC	YES			Plastic bag (cont1 for solid materials)
249	YES	—	YES	—	BAG PAPER	YES			Paper bag (cont1 for solid materials)
250	—	YES	—	—	OTHER	YES			Packages or containers checked on board an aircraft by a passenger in addition to luggage
251	YES	—	—	YES	OTHER	YES			Barge (use only if spill occurred during loading or unloading)
252	—	YES	YES	—	BARREL/KEG WOOD	YES			Wooden barrel (cont1 for solid materials)
253	YES	—	—	YES	CYLINDER BULK	NO	19270701	178.31a 2	Cylinder, 150 to 2000 pounds water volume F RAIL TRANSPORT ONLY
254	YES	—	—	YES	OTHER	YES			Portable bin (cont1 for solid materials)
255	YES	—	—	—	OTHER	YES			Reporter left container blank
256	YES	—	—	—	BOTTLE	YES			Bottle, plastic or glass not specified, capacity 2 gallon or less
257	YES	—	—	—	BOTTLE	YES			Glass bottle, capacity 2 gallons or less
258	YES	—	—	—	BOTTLE	YES			Plastic bottle, capacity 2 gallons or less
259	—	YES	YES	—	BOX	YES			Box, wood or fiberboard not specified
260	—	YES	YES	—	BOX FIBER	YES			Fiberboard box or carton
261	—	YES	YES	—	BOX METAL	YES			Metal box
262	—	YES	YES	—	BOX WOOD	YES			Wooden box
263	—	YES	—	—	OTHER	YES			Case made of wooden frame with wire cover (cont2 only)
264	YES	—	YES	—	CAN	YES			Can, other than metal or aluminum
265	YES	—	—	—	CAN	YES			Aerosol can (contents under pressure)
266	YES	—	—	—	CAN	YES			Aluminum can
267	YES	—	YES	—	CAN	YES			Fiberboard can
268	YES	—	YES	—	CAN	YES			Metal can, capacity 7 gallons or less
269	YES	—	—	—	CARBOY	YES			Carboy, other than glass or plastic or material unspecified, capacity 5 gallons or more
270	YES	—	—	—	CARBOY	YES			Glass carboy, capacity 5 gallons or more
271	YES	—	—	—	CARBOY	YES			Plastic carboy, capacity 5 gallons or more
272	—	YES	YES	—	CONTAINER	YES			Plastic carton or box (cont2 primarily)
273	YES	—	YES	—	CONTAINER	YES			Container, no description given (do not use if at all possible)
274	YES	—	—	—	INSIDE CONTAIN	YES			Glass container, no capacity or description given
275	YES	—	—	—	RAM CONTAINER	YES			Lead container used as shielding for inner container of radioactive materials
276	YES	—	—	—	INSIDE CONTAIN	YES			Plastic container, no capacity or descripti given
277	—	YES	—	—	OTHER	YES			Molded styrofoam overpack for bottles, jugs or carboys
278	YES	—	—	—	CYLINDER	YES			Cylinder, a pressure vessel for compressed gases

* See codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTWO.DMS	CONT2

CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

ABBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
279	YES	—	—	—	OTHER	YES			Cylindrical metal container, not for compressed gases (i. e., not a pressure vessel)
280	YES	—	YES	—	DRUM	YES			Drum - fiber, metal or plastic not specified
281	—	YES	YES	—	DRUM NON-METAL	YES			Fiber drum, cont1 for solids, cont2 for liquids
282	YES	—	YES	—	DRUM METAL	YES			Metal drum
283	YES	—	—	—	DRUM NON-METAL	YES			Plastic drum
284	YES	—	—	—	DRUM NON-METAL	YES			Rubber drum
285	YES	—	—	—	OTHER	YES			Steel or iron flask for the shipment of mercury
286	YES	—	—	YES	HOPPER	YES			Rail hopper car for solid materials only
287	YES	—	—	YES	HOPPER	YES			Highway hopper trailer for solid materials only
288	YES	—	—	YES	CYLINDER BULK	NO	19270701	173.31a 2	Cylinder, 1700 pounds water volume FOR RAIL TRANSPORT ONLY
289	YES	—	—	YES	TANK INTERMODAL	YES		178.271	Steel portable tank
290	YES	—	—	YES	TANK INTERMODAL	YES		178.272	Steel portable tank
291	YES	—	—	—	JAR	YES			Jar, glass, plastic or earthenware not specified
292	YES	—	—	—	JAR	YES			Glass jar
293	YES	—	—	—	JAR	YES			Plastic jar
294	YES	—	—	—	JUG	YES			Jug, glass or plastic not specified, capacity more than 2 gallons and less than 5 gallons
295	YES	—	—	—	JUG	YES			Glass jug, capacity more than 2 gallons and less than 5 gallons
296	YES	—	—	—	JUG	YES			Plastic jug, capacity more than 2 gallons and less than 5 gallons
297	YES	—	—	—	KEG METAL	YES			Metal keg
298	—	YES	YES	—	BARREL/KEG WOOD	YES			Wooden keg
299	YES	—	—	—	INSIDE CONTAIN	YES			Plastic liner for fiber drums and boxes or metal drums containing liquids
300	YES	—	YES	—	OTHER	YES			Passenger luggage on bus or aircraft
301	—	YES	—	—	OTHER	YES		178.315	For liquid nitroglycerin or diethylene glycol dinitrate
302	—	YES	—	—	OTHER	YES		178.318	Container for blasting caps
303	YES	—	—	YES	TANK	NO		173.33	Cargo tanks
304	YES	—	—	YES	TANK	NO		173.33	Cargo tanks
305	YES	—	—	YES	TANK	NO		173.33	Cargo tanks
306	YES	—	—	YES	TANK	NO		173.33	Cargo tanks
307	YES	—	—	YES	TANK	NO		173.33	Cargo tanks
308	YES	—	—	YES	TANK	NO		173.33	Cargo tanks
309	YES	—	—	YES	TANK	YES		178.341	Cargo tanks
310	YES	—	—	YES	TANK	YES		178.342	Cargo tanks
311	YES	—	—	YES	TANK	NO		173.33	Cargo tanks

* See codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTWO.DMS	CONT2

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CONTAINER ABBREVIATIONS AND SPECIFICATION NUMBERS

ABBR. OR SPEC NO.	USUALLY CONT1	USUALLY CONT2	CAN BE EITHER	BULK** CONTAINER	TYPE	NEW CONSTR	DATE CONSTR CANCELLED	CFR 49 SECTION	CONTAINER DESCRIPTION
312	YES	—	—	YES	TANK	NO		173.33	Cargo tanks
313	YES	—	—	YES	TANK	YES		178.343	Cargo tanks
314	YES	—	—	YES	TANK	NO		173.33	Cargo tanks
315	YES	—	—	YES	TANK	YES		178.337	Cargo tanks
316	YES	—	—	YES	TANK CRYO	YES			Cargo tanks for cryogenic liquids
317	YES	—	—	—	OTHER	YES			Used on battery reports when reporter stated no packaging used
318	YES	—	YES	—	PAIL	YES			Pail, open head, capacity 10 gallons or less
319	YES	—	YES	—	DRUM METAL	YES			Metal pail, open head, capacity 10 gallons or less
320	YES	—	—	—	DRUM NON-METAL	YES			Plastic pail, open head, capacity 10 gallons or less
321	YES	—	—	—	OTHER	YES			Pallet, used only for battery reports when no other container given
322	YES	—	—	YES	TANK	YES			Non-portable tank
323	YES	—	—	YES	TANK CAR	YES			Railroad tank car
324	YES	—	—	YES	TANK	YES			Portable tank
325	YES	—	—	YES	TANK	YES			Portable rubber tank
326	YES	—	—	YES	TANK	YES			Storage tank
327	YES	—	—	YES	TANK	YES			Tank truck, tank mounted on truck chassis
328	YES	—	—	YES	TANK	YES			Tank trailer, semi-trailer or full trailer (two axles)
329	YES	—	—	—	TUBE	YES			Squeeze tube
330	—	YES	YES	—	TUBE	YES			Fiber tube
331	YES	—	—	—	TUBE	YES			Glass tube
332	—	YES	YES	—	TUBE	YES			Mailing tube, fiberboard
333	—	YES	—	—	RAM CONTAINER	YES		173.393b	Type A container for radioactive materials
334	—	YES	—	YES	RAM CONTAINER	YES		173.398c	Type B containers for radioactive material(includes small packages thru large casks)

* See codes on last page

** Bulk containers can only be CONT1 (Inner Containers)

Data Base	Attribute
HAZMAT.DMS	CONT1
CANTWO.DMS	CONT2

```
  CODES USED IN BULK_OR_NONBULK ATTRIBUTE
--------------------------------------------
  CODE  ----------DESCRIPTION----------

   1    Package Freight(Non-Bulk)

   2    Bulk Highway Container

   3    Bulk Rail Container

   4    Bulk Intermodal Container

   5    Bulk Water Container
   6

   7
```

```
   CODES USED IN TYPE_OF_RECORD ATTRIBUTE
---------------------------------------------
CODE  --------------DESCRIPTION--------------

 1    Generic container name used when no
      specification container is given
 2    Old specification container, continued
      use allowed, no new construction
 3    Current D.O.T. specification container
      found in CFR 49 Part 178
 4    Old specification container, no longer
      authorized for hazardous materials
 5    Proposed specification container
 6    Performance specification for
      radioactive material container
 7    Specification converted during
      reconditioning, 17E/17H
```

```
      CODES USED IN RESTRICTION_CODE ATTRIBUTE
------------------------------------------------
CODE ABBREVIATION  ---------DESCRIPTION----------

 1   RHA           Removable Head Authorized
 2   RHR           Removable Head Required
 3   RHNA          Removable Head Not Authorized
 4   NRC           Non-Reusable Container
 5   STC           Single Trip Container
 6   A/C           For Aircraft Use
 7   STC-RHA       Single Trip Container &
                   Removable Head Authorized
 8   STC-RHNA      Single Trip Container &
                   Removable Head Not Authorized
 9   STC-RHR       Single Trip Container &
                   Removable Head Required
10   NRC-RHA       Non-Reusable Container &
                   Removable Head Authorized
11   NRC-RHNA      Non-Reusable Container &
                   Removable Head Not Authorized
12   NRC-RHR       Non-Reusable Container &
                   Removable Head Required

PROGRAM:  CANALX.DMC
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APPENDIX B

DESCRIPTION OF FAILURE MODES AND CAUSE CODES

FAILURE MODES

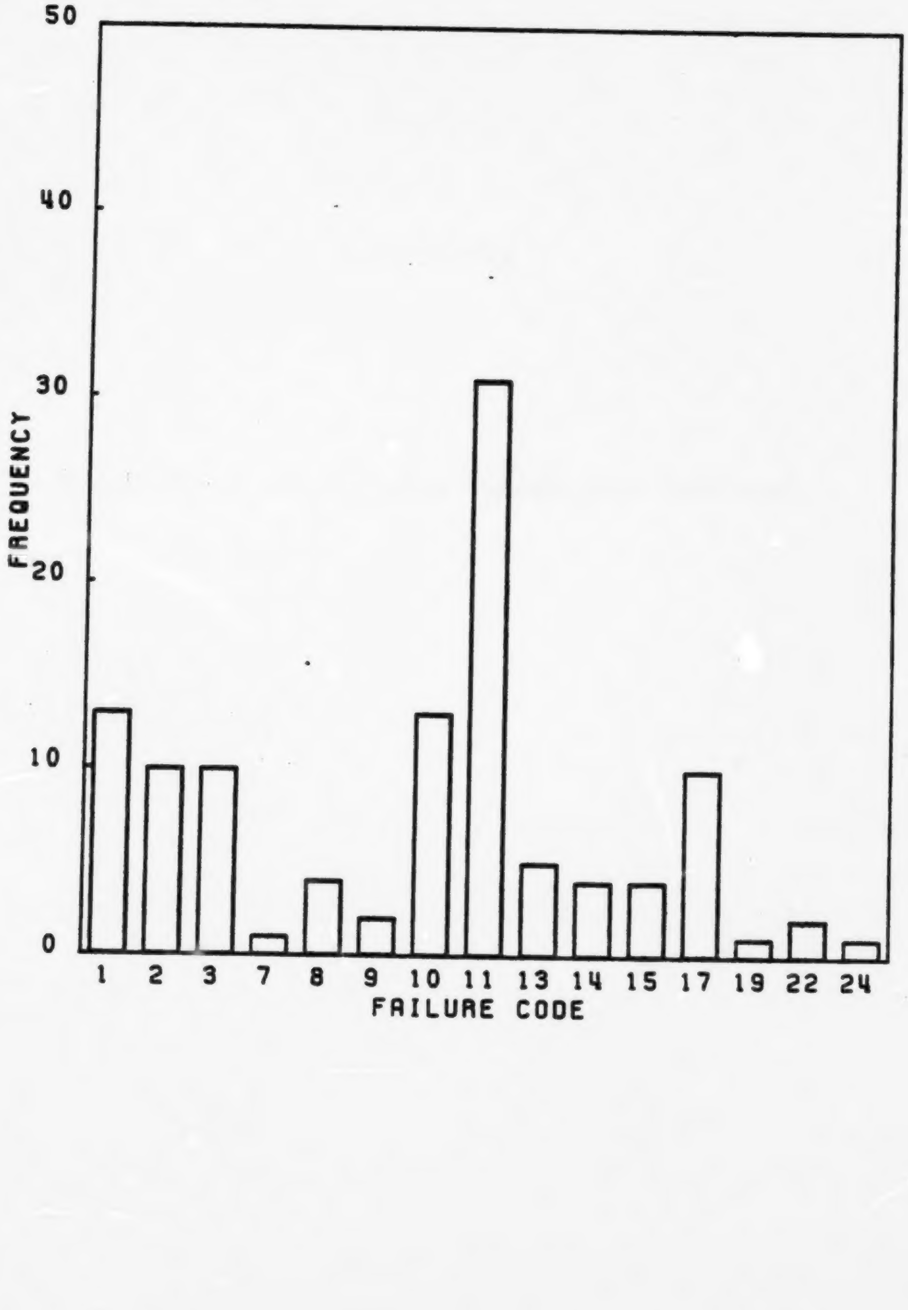
Code Number	Abbreviation	Description
01	DROPPED	Dropped in Handling
02	EXT PUNCT	External puncture
03	OTHER FRT	Damage by other freight
04	WATER	Water Damage
05	OTHER LIQ	Damage from other liquid
06	FREEZING	Freezing
07	EXT HEAT	External heat
08	INT PRESS	Internal pressure
09	CORR-RUST	Corrosion or rust
10	DEF FVC	Defective fittings, valves or closures
11	LOOSE FVC	Loose fittings, valves or closures
12	INNER REC	Failure of inner receptacles
13	BOTTOM	Bottom failure
14	BODY-SIDE	Body or side failure
15	WELD	Weld failure
16	CHIME	Chime failure
17	OTHER	Other conditions
18	HOSE BUST	Hose burst during loading/unloading of tank trucks
19	LOAD-UNLD	Loading/unloading spill (involving tank trucks and trailers)
20	IMP BLOCK	Improper blocking/bracing (cargo shifted, fell over, etc.)
21	IMP LOAD	Improper loading (upside down, on the side, heavy freight on top)
22	VEH ACC	Vehicular accident or derailment
23	VENTING	Venting (automatic or intentional manual venting)
24	FUMES	Release of fumes only (any type of container)
25	FRICTION	Friction (between containers or containers and vehicle)
26	STAT ELEC	Static electricity
27	METAL FTG	Metal fatigue

CAUSE CODES

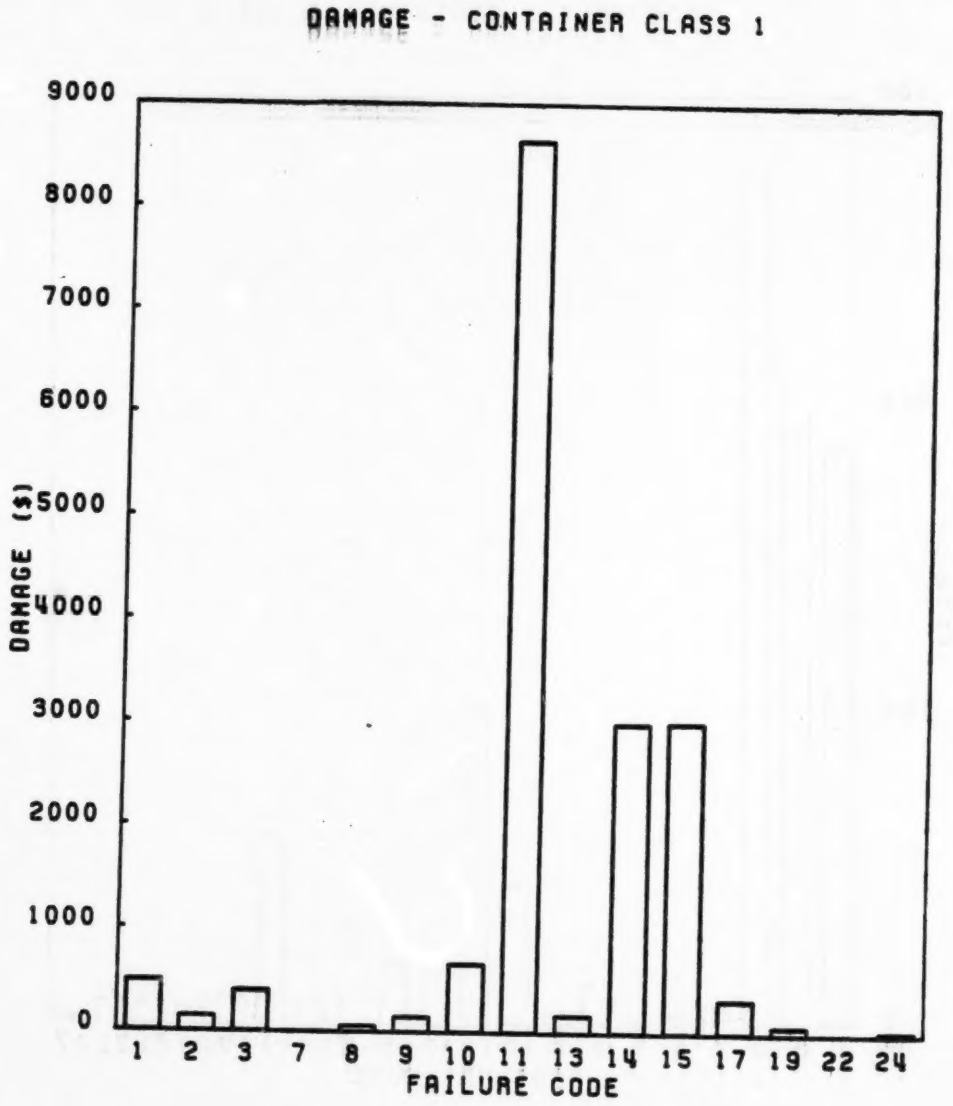
Code Number	Description
01	Human error
02	Package failure
03	Vehicular accidents
04	Other

APPENDIX C

INCIDENT FREQUENCY AND DAMAGE HISTOGRAMS



FREQUENCY - CONTAINER CLASS 1


DAMAGE - CONTAINER CLASS 1
DAMAGE ($)
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8000
7000
6000
5000
4000
3000
2000
1000
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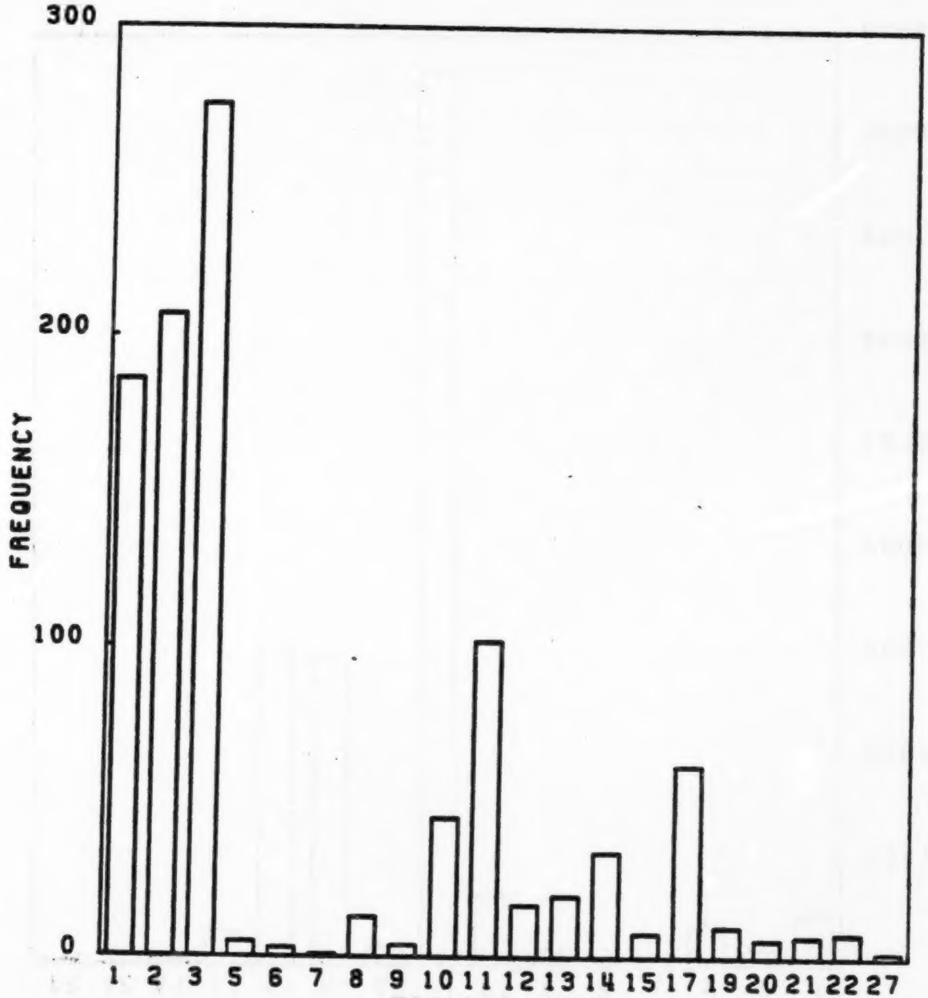
7
8
9
10
11
13
14
15
17
19
22
24
FAILURE CODE

FREQUENCY - CONTAINER CLASS 2



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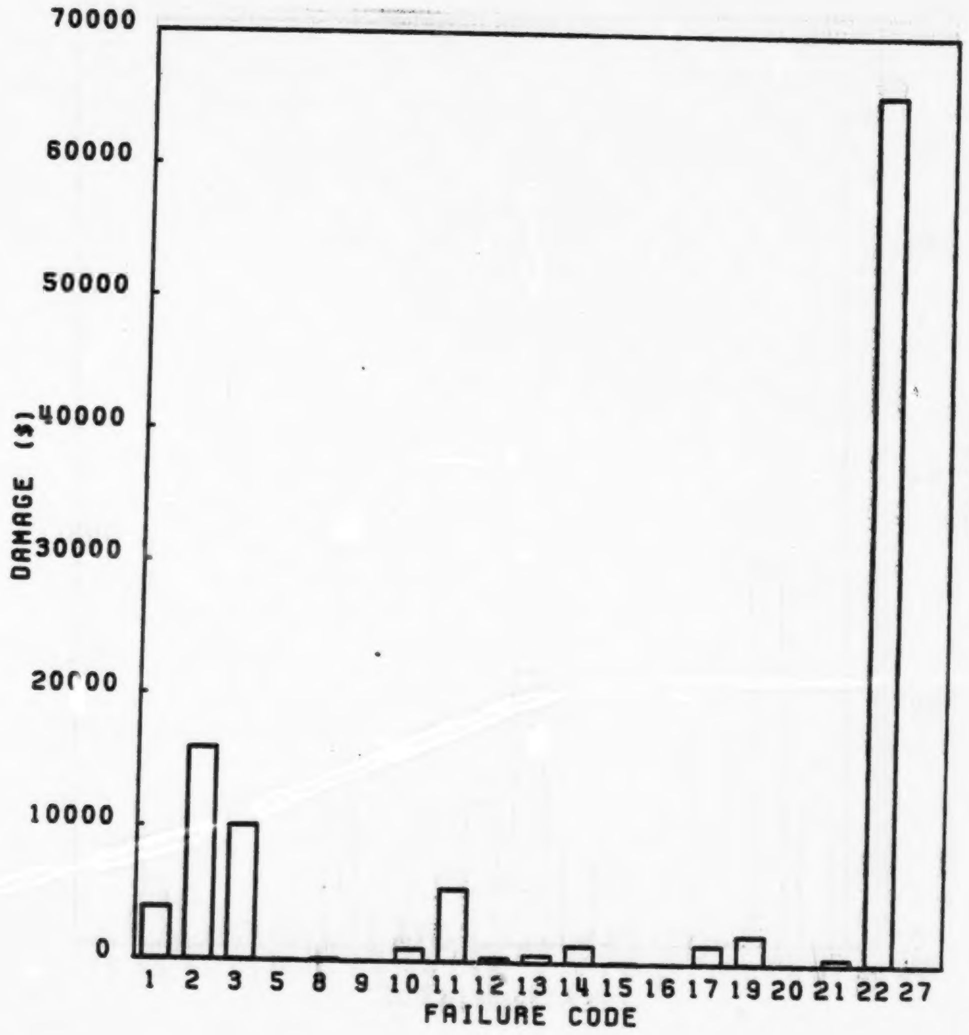

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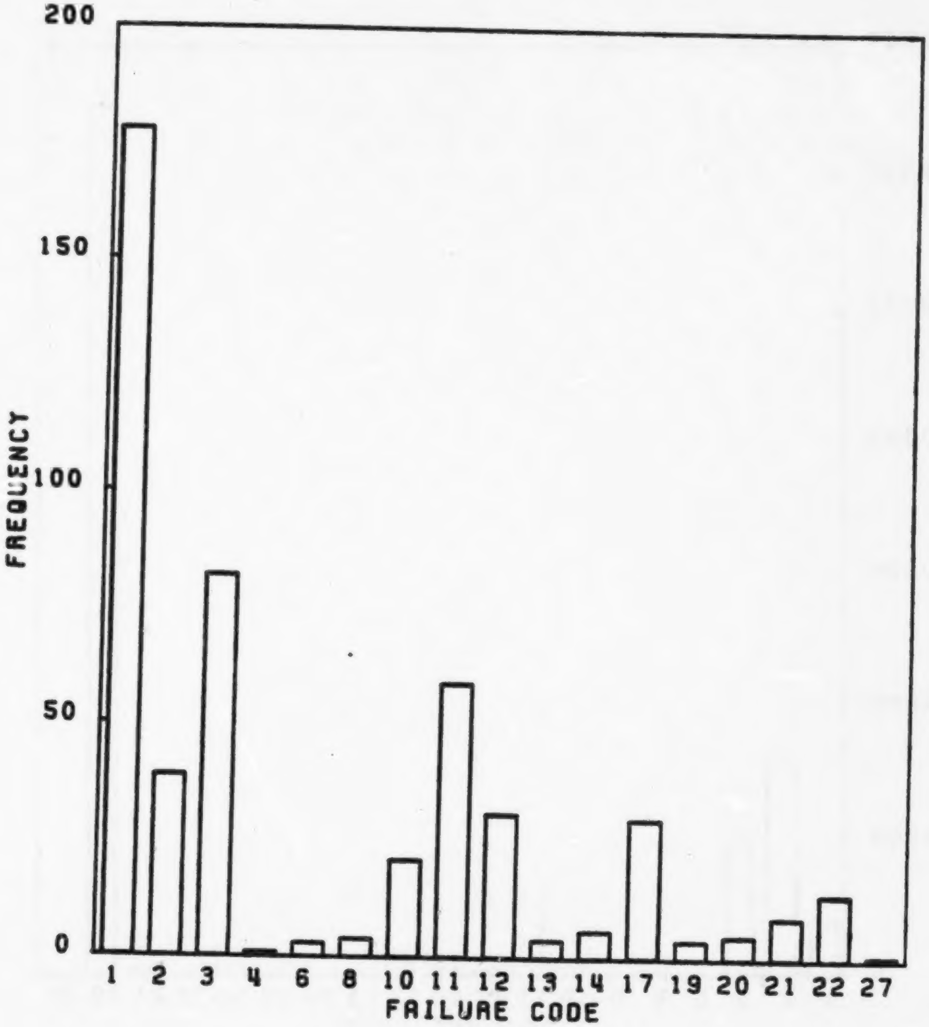

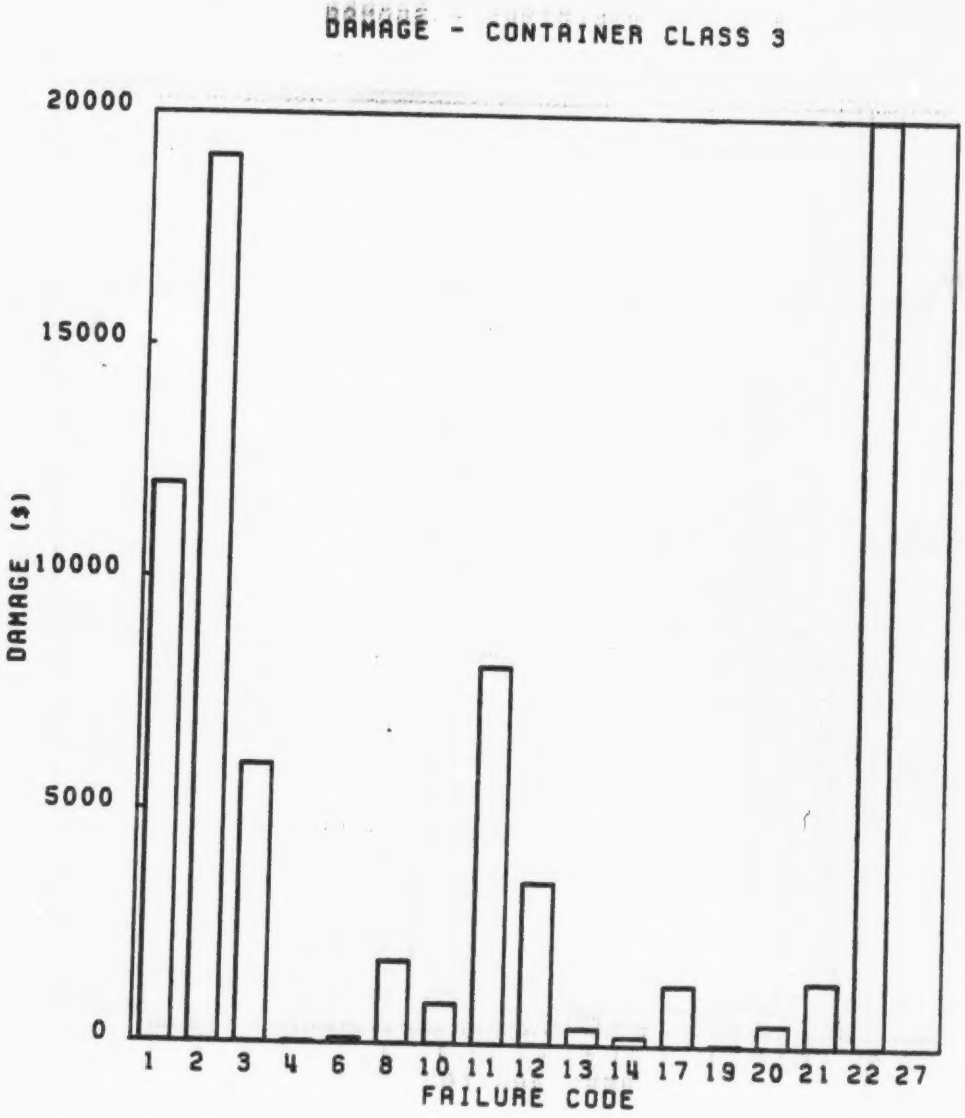
DAMAGE - CONTAINER CLASS 3
DAMAGE ($)
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15000
10000
5000
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4
6
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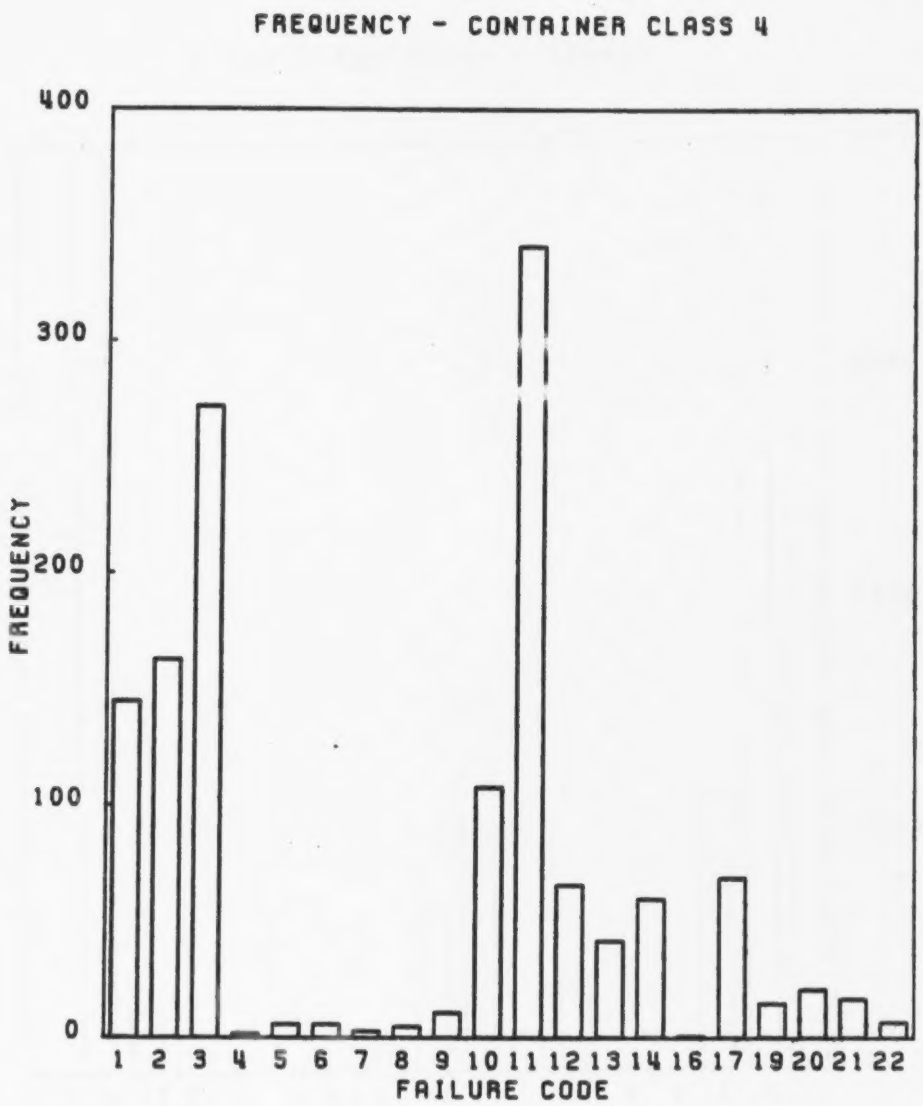
17
19
20
21
22
27
FAILURE CODE


FREQUENCY - CONTAINER CLASS 4
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300
200
100
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FREQUENCY
1
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3
4
5
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16
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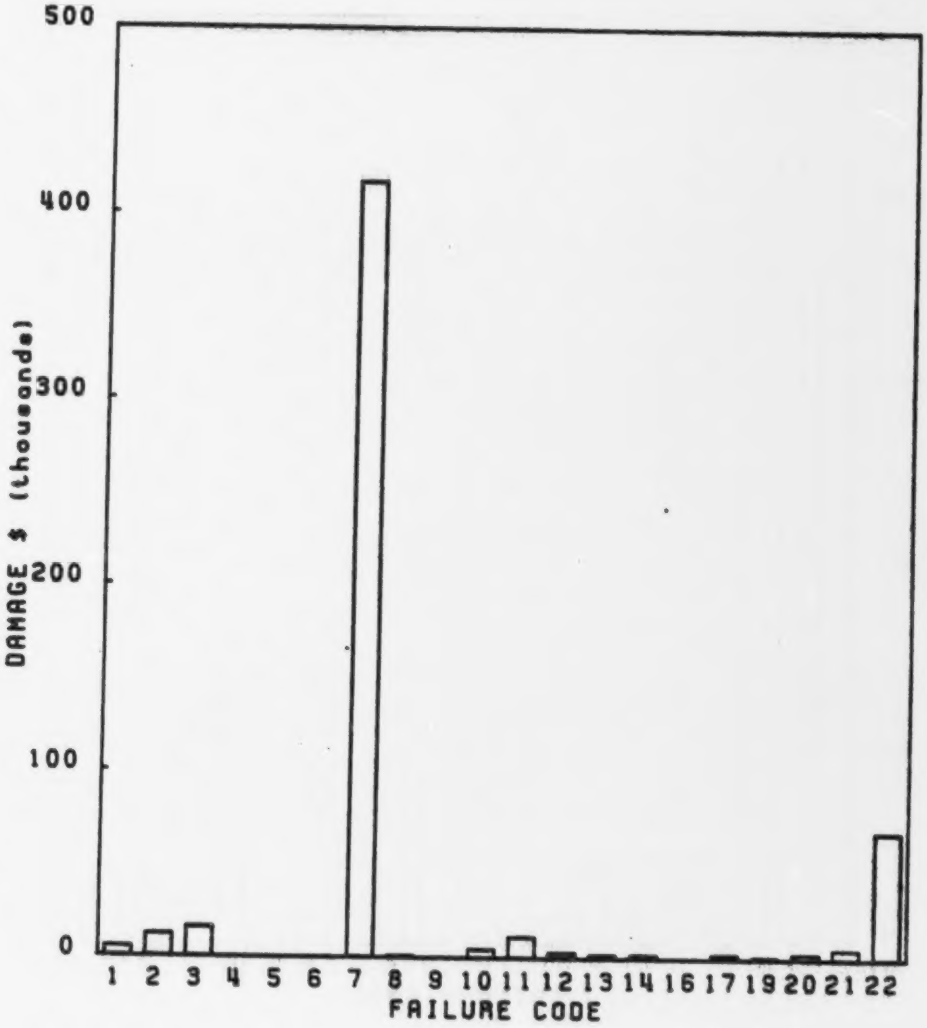
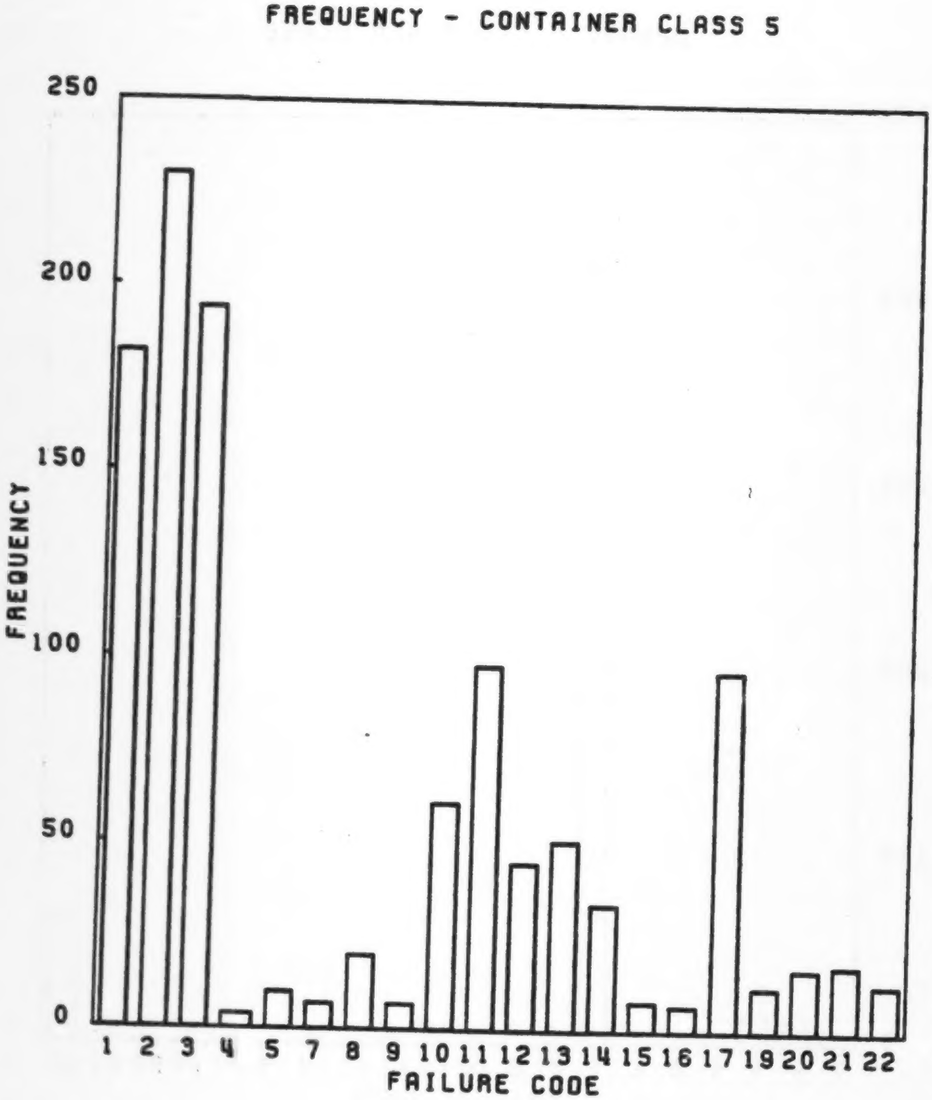
21
22
FAILURE CODE

DAMAGE - CONTAINER CLASS 4

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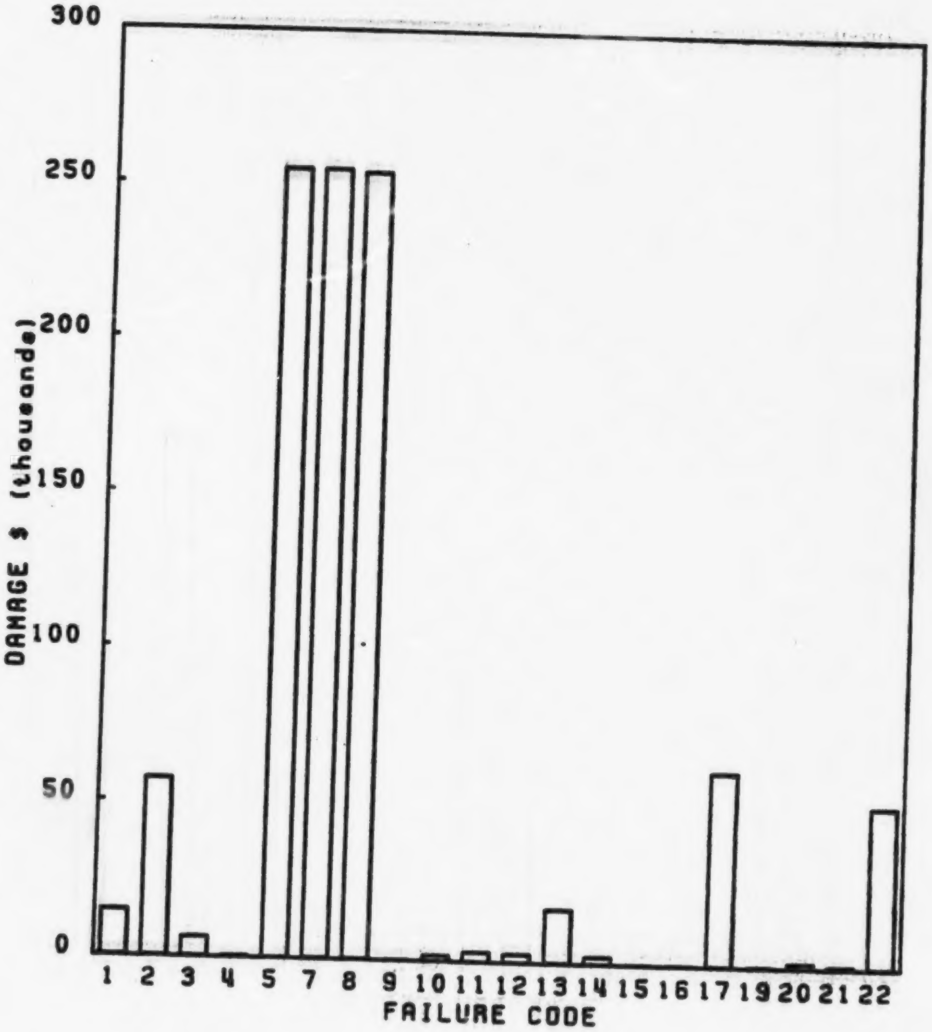
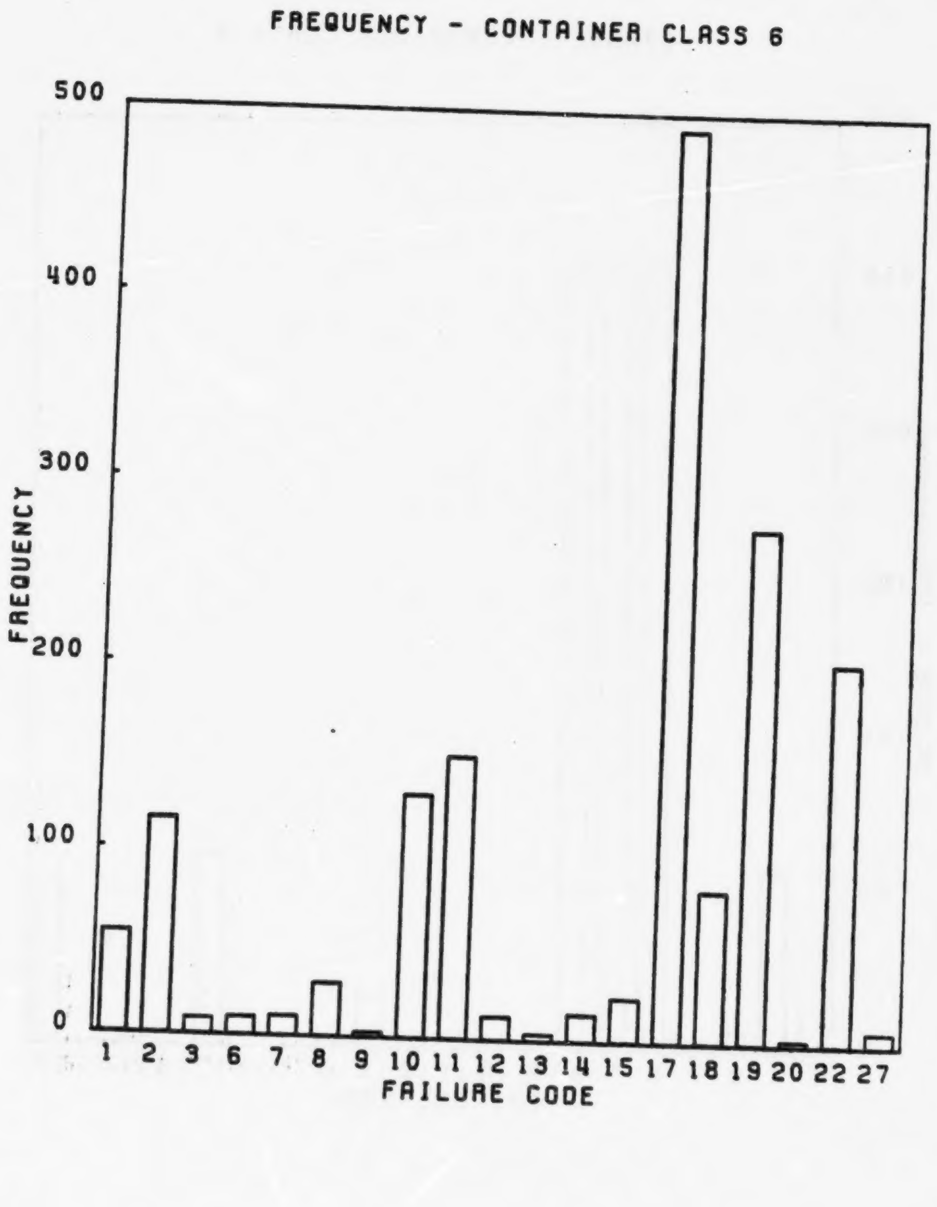
FREQUENCY
250
200
150
100
50
0
1
2
3
4
5
7
8
9
10
11
12
13
14
15
16
17
19
20
21
22
FAILURE CODE

DAMAGE - CONTAINER CLASS 5




FREQUENCY - CONTAINER CLASS 6
FREQUENCY
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400
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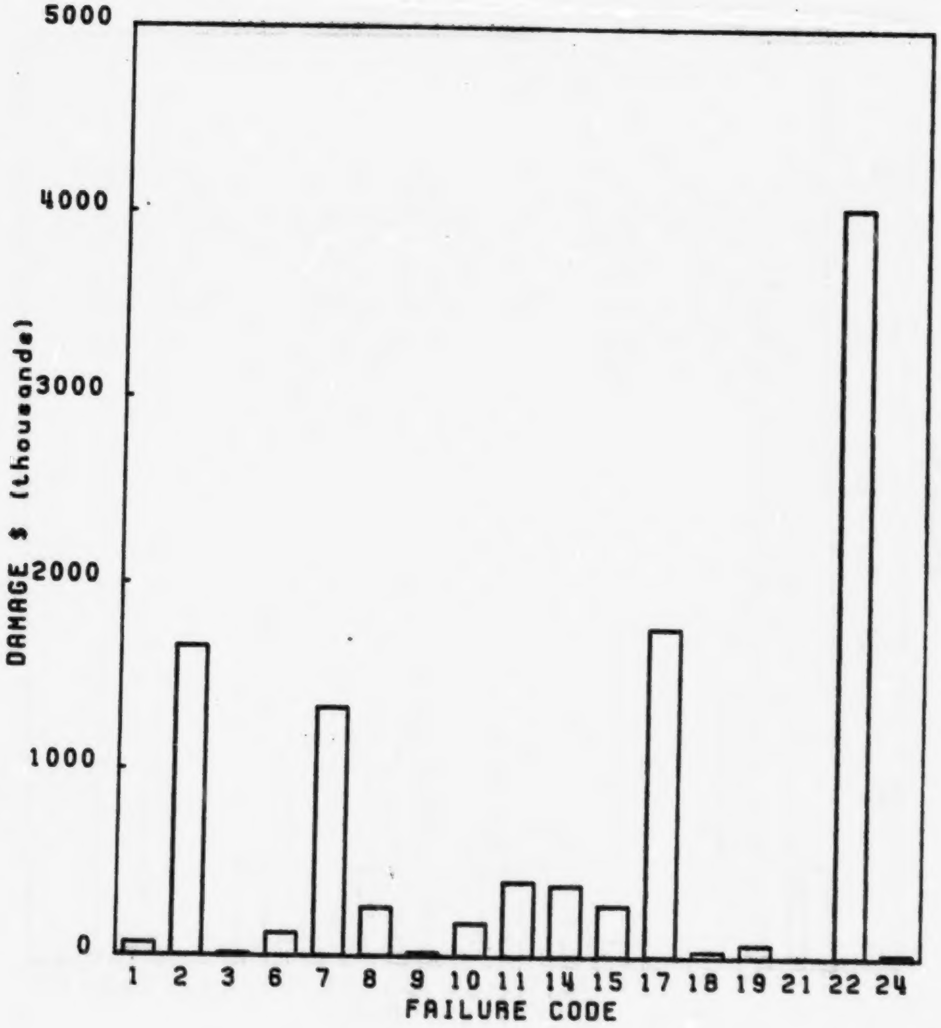
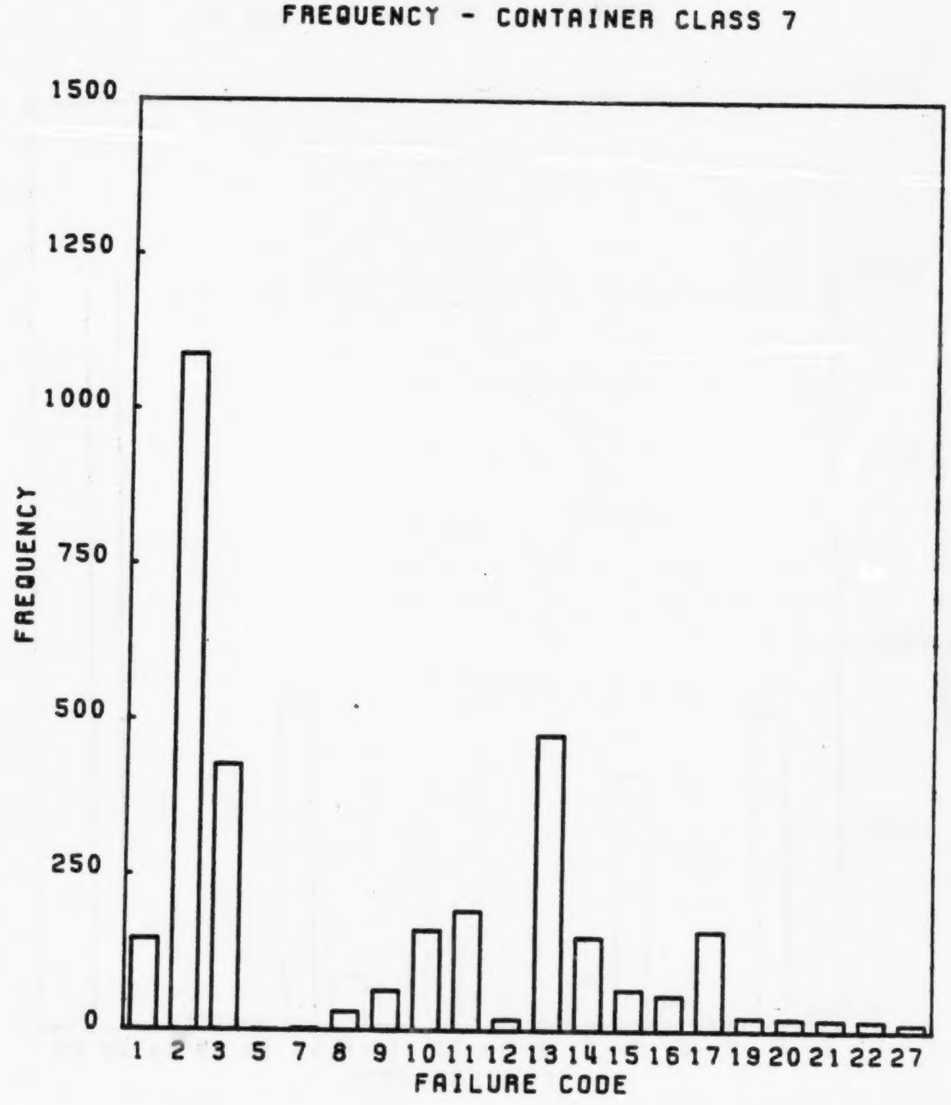
200
100
0
1
2
3
6
7
8
9
10
11
12
13
14
15
17
18
19
20
22
27
FAILURE CODE

DAMAGE - CONTAINER CLASS 6




FREQUENCY - CONTAINER CLASS 7
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1250
1000
750
500
250
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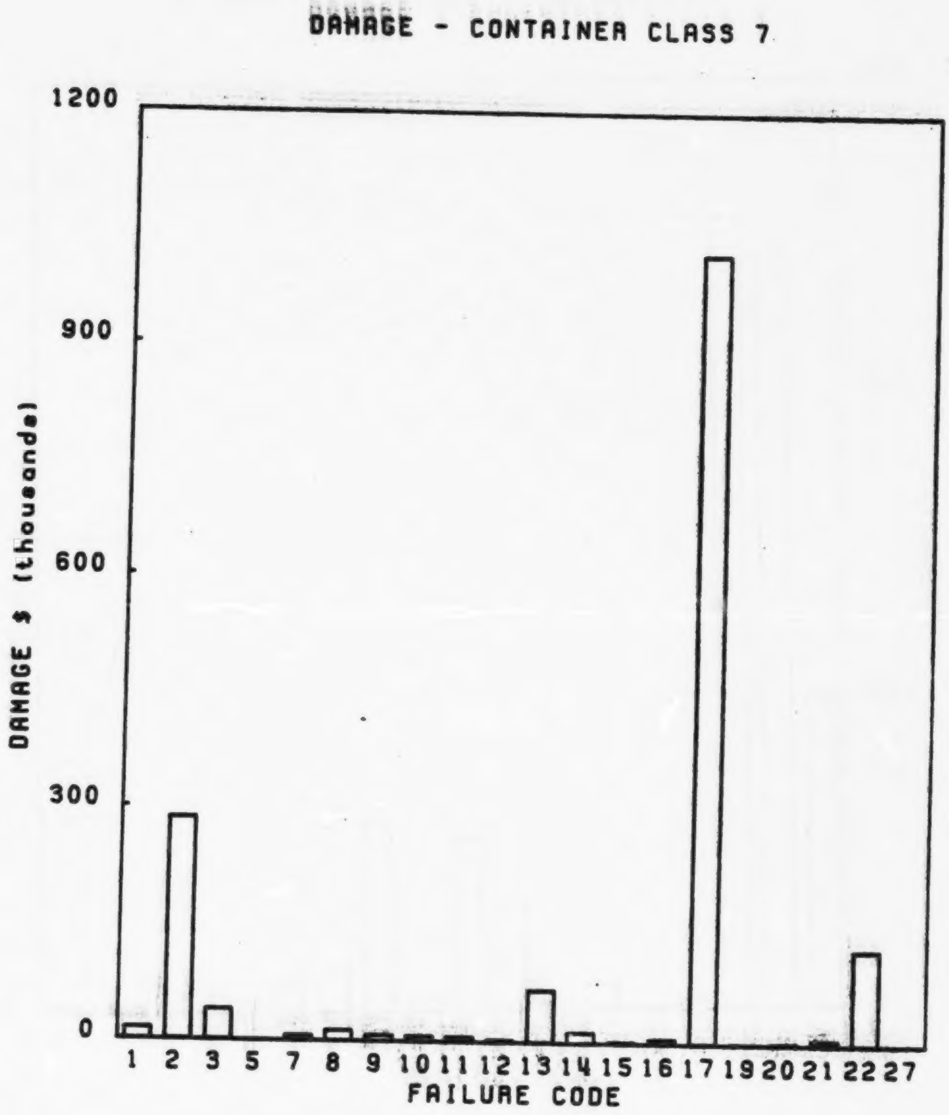
FREQUENCY
1
2
3
5
7
8
9
10
11
12
13
14
15
16
17
19
20
21
22
27
FAILURE CODE


DAMAGE - CONTAINER CLASS 7
1200
900
600
300
0
DAMAGE $ (thousands)
1
2
3
5
7
8
9
10
11
12
13
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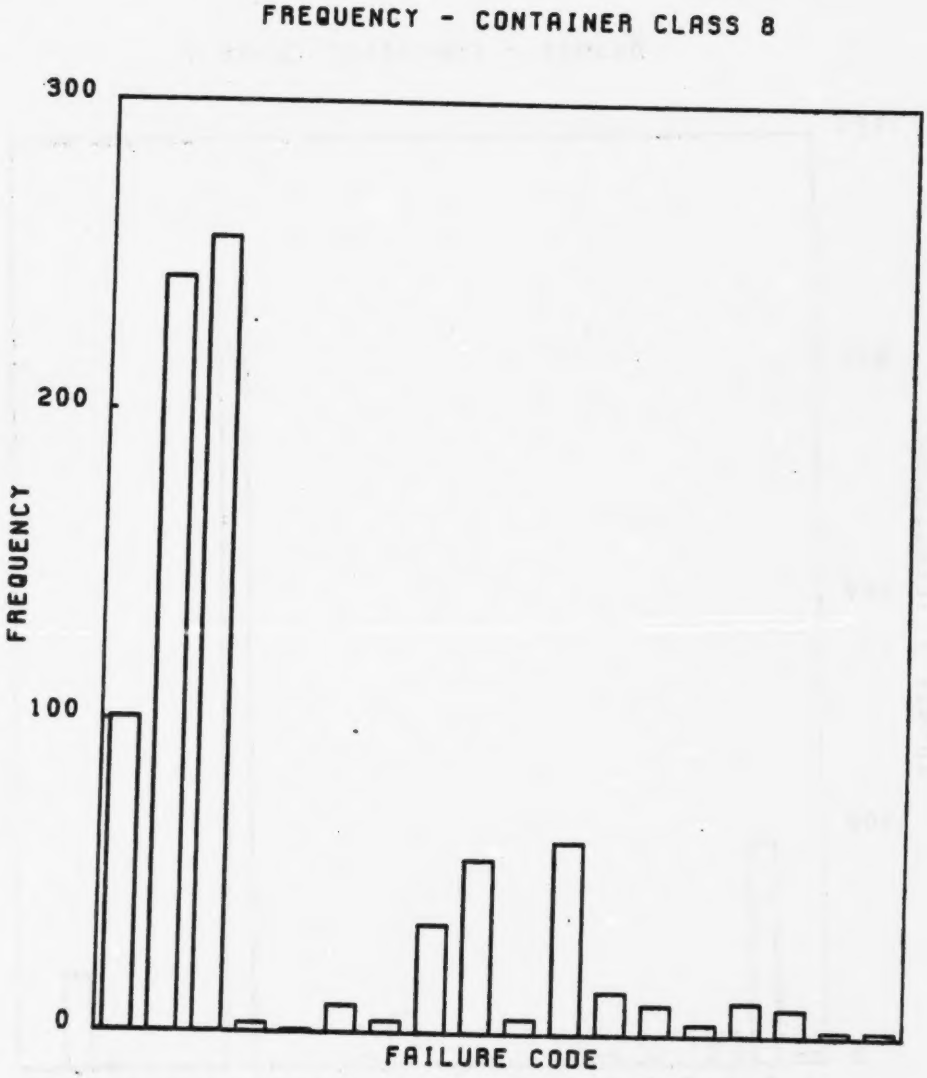
27
FAILURE CODE


FREQUENCY - CONTAINER CLASS 8
300
200
100
0
FREQUENCY
FAILURE CODE

DAMAGE - CONTAINER CLASS 8